REPORTS ON AN EXPLORATION OFF THE WEST COASTS OF MEXICO, CENTRAL AND SOUTH AMERICA, AND OFF THE GALAPAGOS ISLANDS, IN CHARGE OF ALEXANDER AGASSIZ, BY THE U. S. FISH COMMISSION STEAMER "ALBATROSS," DURING 1891, LIEUT. COMMANDER Z. L. TANNER, U. S. N., COMMANDING.

# I.

# CALAMOCRINUS DIOMEDÆ,

## A NEW STALKED CRINOID,

## WITH NOTES ON THE APICAL SYSTEM AND THE HOMOLOGIES OF ECHINODERMS,

## BY ALEXANDER AGASSIZ.

## WITH THIRTY-TWO PLATES.

From the time the Crinoids which form the subject of this Memoir came into my hands, I have been in constant correspondence with my late friend, PHILIP HERBERT CARPENTER, regarding the many points of interest suggested by their discovery.

I can now only have the melancholy satisfaction of inscribing to his memory a monograph which I had hoped to dedicate to him as an expression of my admiration for his researches in a field where we had long been fellow workers.

ALEXANDER AGASSIZ.

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# INTRODUCTION.

Among the most interesting Echinoderms collected by the U. S. Fish Commission Steamer "Albatross," on her voyage from New York to San Francisco, are the Crinoids, which form the subject of this paper.

They were collected at the Galapagos (off Indefatigable Island) in 392 fathoms. The material at my command consisted of one calyx badly torn in being detached from its stem, with fragments of arms in sufficient numbers to enable me to reconstruct two arms completely; a second calyx, with quite a perfect disk and the base of all the arms attached, as well as a short piece of the stem; and a third calyx, with parts of the arms and a portion of the upper part of the stem. This is the best preserved calyx. Numerous fragments and longer or shorter pieces of the arms belonging to these three specimens were collected, as well as pieces and fragments of the stems. Fortunately, the portions of the stem which fitted on the calyx were preserved for each specimen.

During the last dredging trip of the "Albatross," (February to May, 1891,) which I was fortunate enough to accompany, we obtained off Mariato Point, in 782 fathoms, an additional specimen of Calamocrinus Diomedæ. When it first came out of the water it was of a brilliant lemon-color, with a greenish tinge on the sides of the arms and along the food furrows of the ventral surface. A colored sketch of the specimen was at once made by Mr. Westergren, and this is reproduced in Plate XXVIII. of this memoir. Some minor differences in the structure of the stem are also shown in the same plate, and more fully described in their proper place in the memoir. Its base of attachment came up with a fragment of stem nearly fourteen inches long.

At first glance I was inclined to consider this Crinoid, from the characters of its stem, of the spreading uppermost joints, and of its interradial

system, as a modern representative of Apiocrinus.   A more careful exami-
nation has shown many points of difference. and I propose to establish a
new genus for this Crinoid. one of the most interesting brought to light
by any of the deep-sea dredging expeditions.

It is most closely allied to a large group of Mesozoic Crinoids, and helps
us to understand more clearly many points in their morphology which
were left somewhat doubtful from our imperfect knowledge of the Jurassic
Apiocrinidæ.   In a preliminary notice of this Crinoid.[*]  I proposed for it
the name of Calamocrinus Diomedæ.[†]

The first genus of the family (Encrinus) makes its appearance in the
Muschelkalk, and is specially characteristic of that formation.   The Apio-
crinidæ first appear in the inferior Oölite (Millericrinus).   In the upper
beds of the Great Oölite we find Eugeniacrinus and Apiocrinus, the latter
extending to the Coral Rag.

In the Oxford Clay and Coral Rag. Guettardicrinus and Millericrinus
abound, together with Apiocrinus.   In these beds Millericrinus attains its
maximum development, but it also disappears entirely, as well as the other
Apiocrinidæ. in the upper beds of the Oölite.   They have not been found
in the lower Cretaceous. but again make their appearance in the White
Chalk (Bourgueticrinus).   They have not as yet been discovered in the
Tertiary. but they. or their allies. have been brought to light in the deep
seas of the present day (Rhizocrinus and Calamocrinus).

It is interesting, in view of the discovery of so many genera of Crinoids
by the recent deep-sea explorations. to recall the speculations of D'Orbigny [‡]
on their probable existence in our seas.   He says : —

"Tous ces genres et ces espèces qui ont peuplé les mers à des époques
reculées. parurent longtemps n'avoir pas survécu aux époques géologiques ;
au moins. en scrutant les annales de la science était-on tenté de le croire ;
mais je crois aujourd'hui qu'il en existe encore de vivantes. . . .

"M. Saint-Cyr Hotessier . . . a bien voulu me communiquer des échantil-
lons de brèches récentes (de la Guadeloupe). . . . Comme les brèches où
se rencontrent ces restes de Crinoïdes (Bourgueticrinus Hotessieri, D'Orb.)
se forment encore journellement. et qu'elles contiennent seulement des es-
pèces vivantes aujourd'hui. on doit croire que ce Crinoide important existe

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[*] Neues Jahrb. f. Mineral., 1890. I.
[†] Bull. Mus. Comp. Zool.. Vol. XX. No. 6, December. 1890.
[‡] Histoire Naturelle générale et particulière des Crinoïdes vivants et fossiles, comprenant la des-
cription zoologique et géologique de ces animaux, par Alcide D'Orbigny.   3ᵉ Livraison, Paris, 1840.

encore dans les grandes cavités des bans de coraux, et qu'il ne peut manquer d'être découvert un jour. Il parait en conséquence à peu près certain qu'à notre époque, il reste encore aux Antilles un représentant des Apiocrinidées, fait d'autant plus curieux que je possède de ces îles, une espèce vivante de Pentacrinidées, et une Holopicrinidée; en tout trois espèces du même archipel."

This new genus, Calamocrinus, is interesting in having the orals greatly reduced, much as in Bathycrinus. It also possesses heavy perisomic plates, passing gradually into still stouter so called interradial plates in Calamocrinus, in no wise to be distinguished from the true interradials of Palæozoic Crinoids. As will be seen from the description, there are many points in the structure of Calamocrinus which alone go far towards showing how difficult it is to maintain the subdivision into Palæozoic Crinoids and Neocrinoids. But that has been abandoned by Carpenter, though we may all feel how convenient for general purposes of discussion such a subdivision would be.

Liassic Pentacrinidæ, Marsupites, and Uintacrinus all have large massive plates between the rays, which, as in Calamocrinus, are nothing more than greatly developed perisomic plates, though they unite the rays firmly into a very compact whole.

The lowest plates (calyx interradials) have a considerable thickness, and are accurately fitted in between the first and second radials, and they pass gradually into the perisomic plates of the disk, exactly as has been so clearly shown by de Loriol in Guettardicrinus, Apiocrinus Roissyanus, and A. Rathieri.

Wachsmuth has called attention to the significant fact that the vault in the Silurian forms does not acquire that rigid nature which is so characteristic in the Carboniferous, where the vault reached its extreme development. As Wachsmuth has shown, in the Ichthyocrinidæ the ventral structure is very similar to that of the Comatulæ and of Pentacrinus, the nearest approach being found in the Poteriocrinidæ, covered ventrally by a perisome of small irregular plates, and throws considerable light on the question of the constitution of the so called vault of Palæozoic Crinoids, and on the limits of the actinal and abactinal systems.

The study of the ventral surface of Calamocrinus and of its interbrachial areas goes far to prove the correctness of the present views of Wachsmuth and Springer, that the rigid vault as it appears in the Subcarboniferous

in all probability was developed gradually in palæontological time from the disk, and that the vault of the Camerata was in its extreme form an extravagantly developed or modified disk; so that we may with them consider that all the plates between the rays represent the same element, whether they are large or small, heavy or thin, regularly or irregularly arranged, resting upon the basals or the radials, and whether interradial or perisomatic; and that the differentiations which are found among different groups are due to modifications which the Crinoids have undergone palæontologically, — a view which Carpenter in his letters to Wachsmuth and myself fully indorsed.

Another interesting structural feature in Calamocrinus is the limitation of the articular facet to the middle of the radial. This is an eminently embryonic character, and there are traces of it in some of the forms of Millericrinus described by de Loriol in his Jurassic Crinoids, — specially in M. Milleri.

Dr. P. H. Carpenter, in his Report on the Crinoidea of the Challenger (p. 193), says that Leuckart, in his Jahresbericht for 1864 and 1865, divided the Echinoderms into Pelmatozoa, Echinozoa, and Scytodermata, and that, working back from this year, Professor Bell eventually succeeded in tracing this classification of Leuckart's to a morphological essay published in 1848, where, however, the familiar name Actinozoa is used to denote the Urchins and Starfishes together. It is strange that Leuckart's paper on the Morphologie der Wirbellosen Thieren (1848) should not have been familiar to both Bell and Carpenter, for it was in that same essay that Leuckart first established the division of the Cœlenterata which has been so universally adopted by naturalists. This is the more remarkable as in Agassiz's "Contributions to the Natural History of the United States," Vol. I. p. 208, a summary of Leuckart's classification is given in the "Essay on Classification." This Essay on Classification was also published in London in 1859.

The statement made by Carpenter, that the Jahresbericht for 1864 and 1865 contained a division of the Echinoderms into Pelmatozoa, Echinozoa, and Scytodermata, is not correct. Leuckart speaks in that Report of the Scytodermata, Echinida, Asterida, Ophiurida, and Pelmatozoa. The Echinozoa are not mentioned; in fact, the Echinozoa are not mentioned by Leuckart at all in any of his Reports. We find in his Morphologie a first Class of Echinoderms, the Pelmatozoa, with two orders, the Cystids and

the Crinoids ; a second Class, the Actinozoa, with two orders, the Urchins and Asterids (including Ophiurids); and a third Class, the Scytodermata, with two orders, the Holothurians and the Sipunculids. After the publication of his Morphologie, Leuckart himself does not seem to have laid great stress upon some of his suggestions for new classification. In his Report for 1848 to 1853 he only refers incidentally to the name Pelmatozoa, and divides the Echinoderms into, 1. Holothurida, 2. Echinida, 3. Asterida, 4. Ophiurida, 5. Crinoidea. In his Reports for 1854–55 and for 1856 the same nomenclature is followed. In his Report for 1857 he speaks of, 1. Scytodermata, 2. Actinozoa (Echinida, Asterida, Ophiurida), 3. Crinoidea. For 1858 his Report corresponds with that of 1857, and it is only in his Report for 1859 that we find the name Pelmatozoa reappear, ten years later than its first introduction. In his Report for 1859 we find the Echinoderms divided into, 1. Scytodermata, 2. Actinozoa, 3. Pelmatozoa. In 1860 he again drops the name Pelmatozoa, and we find, 1. Scytodermata, 2. Actinozoa, 3. Crinoidea. The same nomenclature occurs again in his Reports for 1861 and 1862, and for 1863. In that for 1864 and 1865 we find the nomenclature as stated in the Report for 1859, Pelmatozoa being again introduced. Then for a series of years, 1866 and 1867, 1868 and 1869, 1870 and 1871, and 1872 to 1875, he speaks in those Reports of Pelmatozoa ; while in the last Reports by Leuckart, in Wiegman's Archiv, he again, 1876 to 1879, introduces, 1. Scytodermata, 2. Actinozoa, 3. Crinoidea.

The name Pelmatozoa was not adopted by any writer on Crinoids except, as Carpenter states, by Sir Wyville Thomson* in the Syllabus of his Lectures ; and, as is seen from what has preceded, Leuckart himself used indiscriminately Crinoidea or Pelmatozoa. It is therefore not surprising that Roemer should not have adopted Leuckart's name, and should have continued to retain the name of Crinoids for the group as a whole, although recognizing the great distinction existing between the Brachiate Crinoids, the Blastoids, and the Cystids.

The confusion which has arisen in the nomenclature of the primary divisions of Echinoderms illustrates the difficulty of attempting to retain old and familiar names as descriptive of groups when limited by more recent or more extended knowledge, or by applying to these older names ideas of nomenclature entirely unknown at the time they were first adopted. To

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* Syllabus of Lectures on Zoölogy, Edinburgh, 1878.

lay great stress upon priority in the case of the nomenclature of orders or families merely introduces endless confusion, and we are compelled either to adopt the principle of limiting the names of well known subdivisions in a manner which in no way conforms to the ideas of the original classifier, or to introduce new names to be changed each time that the limits of these subdivisions are expanded or contracted. Nothing seems to be gained by the use of Scytodermata in place of Holothurians. The Asterida of older authors included the Ophiurans, but to-day the Asterida and Ophiurida are considered as equivalent groups. Yet we might gain precision by adopting a new name to include both these orders, in order to contrast them with the Echinida. We might adopt the name of Actinozoa, or any other, to contrast the Echinids and Starfishes and Brittlestars with the Crinoids on the one hand, and the Holothurians on the other; or again, we might adopt some name to include all the orders of Echinoderms except the Crinoids, and contrast them with the Crinoids; — either of which would represent special points of view seeming to tend toward a subdivision of Echinoderms into groups represented by the genera of the older writers, — Caryocrinus, Pentremites, Pentacrinus, Ophiura, Asterias, Echinus, Holothuria.   These old generic names, or the groups they represent, thus gradually passing into family, ordinal, or even class names of the Branch of Echinoderms.

It is interesting to note how frequently recent investigators are coming back to antiquated classifications under different appellations. As we dwell upon the affinities, or contrast them, in the several groups of the animal kingdom, we find in the specialist a tendency to separate the group he is investigating from those closely allied, while the general morphologist is inclined to unite them.

The Echinodermata of Klein, as he originally defined them, would be limited to Sea-urchins.   The original limitation of Crinoids as defined by Miller would clearly limit them to the Brachiate Crinoids.   Subsequent writers have expanded the limits of Crinoids with increasing acquaintance of the fossil forms, and united to them the Cystids and the Blastoids.   With our greater knowledge of the last named groups, such an intimate association does not seem fully justified, and we are now not seeking affinities, but laying great stress on differences.   No one would suggest the limitation of Echinodermata to the Urchins, and we may ask the same indulgence for the name of Crinoids, retaining that appellation for the group as a

whole. For if we adopt the name Pelmatozoa, we cannot retain the name Crinoidea, which, according to Leuckart, would include the Brachiate Cri- noids as well as the Blastoids, in opposition to the Cystids, — a most un- natural subdivision. We do not express our views of the affinities of Crinoids (*sensu latiore*) by immediately adopting a different primary sub- division of the Pelmatozoa, and suggesting, as is done by Carpenter, that these subdivisions should be Classes of the Branch of Echinoderms, — a proceeding which, under the ordinary rules of nomenclature, would at once do away with the Pelmatozoa as defined by Leuckart.

In suggesting the name Actinozoa of Latreille for the Echini and Asterida, Leuckart exemplifies admirably the confusion consequent upon the practice of applying the nomenclature of the larger subdivisions of the animal kingdom to smaller groups, thus narrowing the limits of the definition. The expansion of these limits to admit new members is not so objectionable.

Latreille in 1824 in his "Esquisse d'une Distribution générale du Règne Animal," (p. 18,) proposed the name Actinozoa, or "animaux rayonnés, . . . avec trois classes, les Holothurites, les Échinodermes, et les Tuniciers," in opposition to the Entozoa ! In his " Familles naturelles du Règne Animal," Paris, 1825, Latreille's Actinozoa form the second Branch of his Acephala, and they include the Tunicates (the third Class of the second Branch), the fourth Class, the Holothurida, and the fifth Class, the Echinoderma. So that Leuckart's limitation of Latreille's name to the Echini and Star- fishes only is very misleading, as Latreille included in his Starfishes the Comatulæ, though he makes a family of the genus Encrinus, the "Caules- centia," and still further includes in his Actinozoa the Helianthoidea as a sixth Class, including the Lucernariæ, Actiniæ, and Zoanthus.

The confusion is still further increased from the general use by English writers of the Actinozoa as limited by Huxley,[*] in which he includes the Polyps and Ctenophoræ ; so that the Actinozoa as understood by most English writers have but little in common with the Actinozoa as originally defined by Latreille, and nothing whatever with the Actinozoa of Latreille as limited by Leuckart.

It is undoubtedly true that Leuckart was the first to contrast the Crinoids or Pelmatozoa with the Holothurians and Actinozoa, but he did not express

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[*] Huxley, T. H., Lectures on the Elements of Comparative Anatomy, London, 1864. Lectures I.-VI. On the Classification of Animals (originally published in the Medical Times and Gazette).

the more important contrast between the Crinoids and the rest of the Echinoderms which has been mentioned by older naturalists, like W. B. Carpenter, Huxley, Metschnikoff, and other writers on the embryology of Echinoderms.

Say had most definite views of the position of Blastoids as a family of Crinoids, yet he still associated the Cystids with the Brachiate Crinoids.

From Von Buch's Monograph on the Cystids it is evident that, while he recognizes their affinities to the Crinoids, yet he also insists on their structural differences, and comes to the conclusion that they stand alone at the beginning of the series formed by the succession of the Crinoids to the Cystideans.

Roemer, however, who made the first exhaustive study of the Blastoidea, placed them as a family in the order of Crinoidea, as the title of his memoir sufficiently shows, "Monographie der fossilen Crinoiden, Familie der Blastoiden." Whether the Blastoids and Cystids are sufficiently distinct to rank as separate classes is more than doubtful, considering, as Carpenter says, the large number of apparently intermediate forms which have been discovered since Roemer wrote. Carpenter himself (Chall. Rep., p. 191) mentions the difficulty of referring forms like Hybocystites and Cystoblastes to one group rather than the other.

The existence of arms, although but slightly developed, and of an articulated stem, and the discovery of several so called transition types between the Brachiate Crinoids and the Cystids would seem sufficiently to indicate their affinity with the Eucrinoids, in spite of the incomplete radial structure of the plates of the body and the presence of the so called hydrospires. Similarly, the presence in the Blastoids of pinnules, which are after all only modified arms, would also indicate a closer structural affinity with the Brachiate Crinoids than Carpenter is willing to admit when contrasting the Blastoids and Cystids, as a subdivision of Echinoderms, with the Brachiate Crinoids.*

* See also Etheridge and Carpenter, Catalogue of the Blastoidea of the British Museum, 1886.

# CALAMOCRINUS DIOMEDÆ.

## THE CALYX.

THE five basals are pentagonal, joining by their long sides; the lower side of the basal in contact with the upper stem joint is slightly longer than each of the upper sides of the basiradial faces. (Plate II. Figs. 1, 2; Plate III. Figs. 1–3.)

The basals are nearly four fifths the height of the primary radials. The diameter of the basal ring at its junction with the stem is about half that of the basal ring at its junction with the radials. The outline of the basal cup seen in profile bulges slightly above its junction with the stem, then forms a slightly re-entering curve, to bulge out again at the junction of the radials, with a second re-entering curve in the middle part of the radials. (See same figures as above.)

The radials are elongate, deeply cut into by the first brachials, which cut out a circular sector extending nearly one third the height of the radial. The vertical sides of the radials flare slightly and the diameter of the calyx gradually increases to the eighth brachial. (Plate II. Figs. 1. 2; Plate III. Figs. 1–3.)

The first brachials do not occupy more than two thirds of the distal edge of the radials; and the deep cut made into the first radials by the first brachials leaves two comparatively short sides of adjoining radials, which separate the first brachials, and are in contact with the rows of heavy imperforate plates forming the proximal part of the perisomic plating. (See same figures as above.)

There is a marked asymmetry in the primary radials which abut against the plating forming the base of the anal proboscis. They are somewhat longer than those of which the sutures face the other interradii. (Plate II. Fig. 2.)

The interbasal sutures are distinct in one of the specimens; in another, they could easily be traced, and became prominent on the application of a little potash. In another fragment of a calyx the vertical sutures of the basals were completely anchylosed. and their lines could not be detected either from the inside or the outside of the basal ring (Plate XIX. Figs. 1–3). The basiradial sutural lines were, however, always distinct, and did not become anchylosed with those of the basals into a solid cup, as is frequently the case in Rhizocrinus. These anchylosed basals were originally described by Sars as forming a calyciform upper stem joint. Its composite structure was first traced by Pourtalès, and subsequently by Carpenter. The anchylosis of the basals is very similar to that of the basals in Bathycrinus, but the proportionate height of the solid ring to the radials is greater in Calamocrinus than in Bathycrinus. where, as Carpenter says, there are no sutures visible externally. The radials ot Bathycrinus are much less closely united; they are thin plates in contact with one another by quite narrow sides. often anchylosed. In Atocrinus of McCoy the basals and lower radials are completely anchylosed. the radial adjoining the anchylosed cup being an axillary.

As in Hyocrinus, the first brachials of Calamocrinus are narrower than the primary radials, but their mode of articulation to these, in a ridge extending along the middle of the radials to a prominent projection on the upper face of the radial, is very different. The mode of articulation of the arms to the radials in Calamocrinus recalls that of such palæozoic genera as Hexacrinus, Platycrinus, Pisocrinus, and Cyathocrinus, in which the brachials are also narrower than the radials.

The basal ring of the imperfect specimen figured on Plate XIX. Fig. 1, is completely anchylosed. and the lines of sutures can only be traced from the interior (Plate XIX. Fig. 3) before the removal of the radiating axial cords from the central part of the ring. The sutures are still indicated by the presence of interarticular ligaments occupying the reticulation adjoining the interbasal sutures. On the outer surface (Plate XIX. Fig. 1) the position of the interbasal sutures is only traced with the greatest difficulty, and no actual line of suture is visible. The grooves in which the radiating cords run on the inner faces of the basals are irregularly massed in groups of five, as is shown in the inner view of the basal ring (Plate XIX. Fig. 2) after the removal of the chambered organ and the radial prolongations of the axial cord (Plate XIX. Fig. 5). The indistinct course

of the radiating grooves for the reception of the radial continuation of the axial cord and of the longitudinal muscular fibres is shown in Plate XIX. Figs. 2 and 4.

The cavity for the chambered organ is entirely within the basal ring, occupying the central part of the excavated basal ring above the opening for the passage of the axial cord and the edge of the larger ring, from which branch off in the grooves of the basal plates the forks of the axial cord leading to the radials.

In Apiocrinus the basals are grooved for the reception of the bifurcating cords, and in Millericrinus Milleri the chambered organ is, according to Carpenter, entirely upon the ventral aspect of the basals.

The proximal face of the first radial (Plate XX. Fig. 5), by which it is united to the basals, is a bevelled surface, which is somewhat irregular on the inner face (Plate XX. Figs. 2 and 5), but with a sharp outer edge, corresponding closely to the outlines of the basiradial sutures of the corresponding basals. It is united to the adjoining radials by a bevelled face, similar to that of the distal face. The thickness of the first radial increases rapidly towards its distal face (Plate XX. Fig. 4, $r\,w$, $r\,w'$), from the sudden development of the proximal and distal wedge-shaped projections $r\,w$ and $r\,w'$ (Plate XX. Fig. 2), which serve as supports for the interradial ligamentary bundles (Plate XX. Fig. 9).

The grooves which carry the axial cords on the ventral face of the radials pierce the first radial in its upper third (Plate XX. Fig. 2), and come out at the distal face in the central part of the ridge which separates the fossa for the dorsal ligaments from the fossæ for the interarticular ligaments and the muscular fossæ (Plate XX. Fig. 3).

The ridges separating the fossæ for the interarticular ligaments from the muscular fossæ are somewhat indistinct, and there appear to be two such fossæ for the interarticular ligaments (Plate XX. Fig. 3). The interarticular ligaments of the second radial ($r^2$, Plate XX. Fig. 2) are much reduced in importance, as is seen in the figure of the proximal face (Plate XX. Fig. 6). There is no trace of a fossa for the interarticular ligament on the distal face of the same radial (Plate XX. Fig. 7), but on one side of the axial canal of the distal face of the third radial there is a marked fossa for the interarticular ligament.

Judging from the figures of the interior of the calyx of several species of Apiocrinus given by de Loriol in the Paléont. Française (Plate 33, Fig. 1ª,

Plate 42, Figs. 1ᵃ, 2ᵃ, Plate 53, Fig. 1ᵃ, Plate 54, Fig. 1ᵃ, Plate 56, Fig. 2), there must have been on the inner faces of the first radials of these species of Apiocrinus projections or protuberances similar in their function to the wedge-shaped projections *r w, r w'*, figured on Plate XX, Fig. 2, for Calamocrinus, which were separated by deep grooves extending from the central part of the radial towards the interradial sutures.

It is interesting to compare the course of the muscular furrows in the radials of Calamocrinus with the excellent figure given by Beyrich (Crinoideen des Muschelkalks, Plate I, Fig. 1ᵇ) of their course as seen in the interior of an Encrinus calyx. They are not always curved in Calamocrinus, as Beyrich considers those of Encrinus to have been, and only sometimes to form free open grooves, as they occur in Calamocrinus, or pass into the thickness of the plates.

In Calamocrinus, as in Hyocrinus, Plicatocrinus, and Marsupites, only the central part of the distal face of the first radial has an articular facet. Carpenter has called attention to the embryonic character of this structure (Pentacrinoid stage of Comatula); it is far more general in the Palæocrinoids than in later forms, where the facets of the first radials occupy the whole width of the distal face of the radial.

In the Mesozoic and later Crinoids the articulation between the first and second radials is effected by a pair of muscles and two ligaments. According to de Loriol, it is absent in Guettardicrinus, in which the reduced articular facet of Apiocrinus has entirely disappeared. The fossæ only make their appearance at a later stage of development. The axial cords at first lie upon their upper surfaces, and are gradually taken more deeply into the substance of the plates; they lie for some time in open canals. According to Carpenter, in many Crinoids the distal faces of the radials remain permanently in the horseshoe condition, with ligaments and muscles but poorly developed.

According to Carpenter, the dorsal ligamentary pit is enormously expanded in Millericrinus and Apiocrinus. The muscular fossæ are symmetrical in the first and second radials, but in ordinary arm joints bearing pinnules they are asymmetrical. The distal angle of the primary radials is not cut away, as in Guettardicrinus, Uintacrinus, and Apiocrinus Roissyanus, to receive the lower part of the first interradials; they are placed in Calamocrinus on the distal edge of the two adjoining radials.

Carpenter says there seems to have been a trifascial articulation between

the two interradials of Apiocrinus insignis. (See de Loriol, Plate 56, Fig. 2ᶜ.) The second radial in Hyocrinus is not wide, but narrow, as in Calamocrinus, a feature which, according to Carpenter, is also characteristic of Millericrinus Milleri, and a few other species.

The calyx, though symmetrical in all Neocrinoids, may undergo distortion (Eugeniacrinidæ, Holopidæ). In Thaumatocrinus and in Calamocrinus, though to a less extent, the anal radials are larger than the others.[*]

## THE ARMS.

Calamocrinus has five arms (Plate II. Figs. 1, 2, Plate III. Figs. 1–3, Plate VI. Fig. 1), and, as far as we can judge from the fragments of the arms which could be reconstructed, there are three forks to the right and two to the left in one case (Plate I. Fig. 1), but in the adjoining arms of the same figure there were evidently three branches on the left and two on the right. Judging from the specimen figured in Plates II. and III., the first branch of the anterior arm was to the left (facing it). The same was the case with the left anterior and the left posterior, while in the right anterior arm the first branch was to the right. In the anterior and left posterior arms the first axillary was the seventh brachial joint (Plate III. Fig. 2); the same was the case in the right and left anterior arms. In another specimen the axillary of the same arm was the eighth brachial, there being three syzygies in this arm, in the first, fourth, and sixth brachials, while in the former case there were three syzygies, in the first, fourth, and fifth brachials. We find the same difference in Plate I. Fig. 1, and in Plate IV. Fig. 1. The second axillary (Plate II. Fig. 1) is the (twelfth brachial) fifth joint from the first axillary in both the anterior and the right anterior arms, while in Plate IV. Fig. 1, it is the sixth joint in that arm. The third axillary is again the sixth joint from the second, while the fourth axillary is the eighth joint from the third axillary. In Plate II. Fig. 1, the second, third, and fourth axillaries are on the same joints as those of the arm of Plate IV. Fig. 1, while the fifth axillary is the eleventh joint from the fourth axillary. In the right arm of Figure I, Plate I., the arrangement of the axillaries is the same, but the fourth axillary is the ninth joint from the third axillary, and not the eighth.

In the arms in which there are seven joints to the first axillary there were syzygial joints on the first, fourth, and sixth joints. In the same arms

* See also Carpenter and Etheridge, Ann. Mag., 1871, p. 285, Allagecrinus.

there were syzygial joints on the second joint between the first and second axillaries, on the second and third joints between the second and third axillaries, and on the first, third, fourth, and sixth, between the third and fourth axillaries.

In the arm figured on Plate I. Fig. 1 (the right arm) there are syzygies on the second and fourth joints between the first and second axillaries; on the second, fourth, and fifth joints between the second and third axillaries; and on the first, third, fourth, sixth, and seventh joints between the third and fourth axillaries.

On the left arm of the same Plate, the first, third, fourth, and fifth joints were syzygial joints between the first and second axillaries; the same was the case with the second, fourth, and fifth joints between the second and third axillaries; while the second, fourth, fifth, and sixth were syzygial joints between the third and fourth axillaries. Between the fourth and fifth axillaries, the first, second, third, fifth, sixth, and seventh joints had syzygial joints.

In the case of the branches, many single joints separate the syzygies; in one branch six and sixteen pinnule-bearing joints intervened between the syzygies, and in another four and eighteen.

As far as the position of the pinnules is concerned, the first pinnule of the anterior arm is on the left of the third brachial (Plate III. Fig. 1); the second is on the right on the epizygial of the fourth; the third on the left again on the epizygial of the fifth brachial; and the fourth on the right on the sixth joint in the same specimen. We find the same arrangement in the order of the pinnules of the other arms in this specimen (Plate III. Fig. 1), while in the specimen on Figure 2 of Plate III. the third pinnule is on the fifth brachial; see also Plate V. Fig. I. On the left posterior arm the first pinnule is on the third brachial, the second on the epizygial of the fourth, the third on that of the fifth, and the fourth pinnule on the sixth brachial, there being four pinnules below the first axillary (Plate II. Fig. 2, Plate V. Fig. 2). This is also the case in other arms, in which there are seven brachials below the first axillary; even when we have only six brachials, there are five pinnules in one case below the axillary (Plate V. Fig. 4).

The first brachials are much wider than the succeeding ones (Plate III. Figs. 1, 2), and the brachials taper gradually towards the first axillary. The lower brachials are somewhat compressed vertically, while both the main

arm and its branches become compressed laterally as the distance from the disk increases (compare Plate III. Figs. 1, 2, and Plate I. Figs. 5–7), and towards the distal end they become quite flattened (Plate I. Fig. 1).

In still another imperfect arm, the third axillary was the eleventh joint beyond the second, and with a syzygy on the fifth arm joint.

The fork to the right had syzygies on the second, third, sixth, twenty-second, and twenty-eighth arm joints, and no others to the end of the fork.

The main arm between the third and fourth axillaries had syzygies on the first, third, and ninth joints.

The fourth axillary was the tenth joint beyond the third, and the fifth the thirteenth beyond the preceding axillary. Between the fourth and fifth axillaries, the main arm had syzygies on the fifth and eighth arm joints. The fork to the right of the fourth axillary had syzygies on the second, fourth, seventh, twelfth, and nineteenth arm joints. The main arm from the fifth axillary to the end of the arm had syzygies on the eleventh, seventeenth, twenty-eighth, thirty-second, thirty-fifth, thirty-eighth, forty-first, forty-third, forty-sixth, fiftieth, fifty-third, fifty-seventh, and sixtieth arm joints.

In a broken arm the first axillary was the seventh brachial. The first fork to the right had syzygies on the second and third joints, and there were twenty-one joints without any, the extremity of the arm being broken at that point.

The second axillary was the seventh arm joint beyond the first, the third the eleventh, and the fourth the twelfth beyond the preceding ones. Between the first and second axillaries, and between the second and third, the third arm joint had a syzygy. Between the third and fourth axillaries, the fourth and eighth joints had syzygies.

In another fragmentary arm the second axillary was the seventh joint, the third the ninth, and the fourth the twelfth joint beyond the preceding axillary. Betwen the second and third axillaries, the third and fifth arm joints had syzygies; between the third and fourth axillaries, the fourth and seventh arm joints.

The second fork had syzygial joints on the second, fourth, and nineteenth arm joints; the third, on the second, third, sixth, fourteenth, twentieth, and twenty-sixth joints; the fourth, on the second and third joints. All these forks branched off to the left of the main arm.

There seems to be considerable irregularity in the number of syzygies in the forks from the main branch of the arms. In the first fork, in one case, there were two syzygies in the second joint; but generally the syzygies of the first fork, whether it be to the right or left, were on the second and third joints.

In the arm on the left in Plate I. Fig. 1, the first branch is on the right, like the one already described, but having an additional intercalated joint with a syzygy, in place of the single joint carrying a pinnule on the right arm of the same interradial. The second branch is missing. The third branch, on the right, begins at the seventeenth joint. Its fourth joint has a syzygy, next the thirteenth joint, then the nineteenth joint, the twenty-sixth, and the thirty-eighth. There are sixty-eight joints in the arm apparently perfect. The fourth branch is also on the right hand side. The first, third, and ninth joints of the main branch between the third and fourth forks have syzygies, and the tenth joint is the axillary of the fourth fork.

The fifth fork is on the left, and the main stem continues apparently as the right hand branch; it has syzygies at the thirteenth, nineteenth, twenty-ninth, thirty-second, thirty-eighth, fifty-eighth, sixty-third, sixty-seventh, seventy-first, and seventy-third joints; and there seem to be seventy-seven joints, the arm appearing perfect. The fifth left hand branch is an imperfect branch, with probably from forty to forty-five articulations.

The axillary of the first fork of the arm on the right (Plate I. Fig. 1) is the eighth brachial. The first fork is on the left, but the branch is at least one third longer than the corresponding branch of the adjacent arm. It has syzygies at the second, fourth, ninth, thirty-third, fortieth, sixty-seventh, seventy-sixth, and eightieth joints, and has eighty-three joints. The main stem branches again at the ninth joint on the right hand side from the first axillary, the third and seventh joints of the main stem having syzygies. Only one joint of this branch is preserved.

At the eighth joint of the main stem, it branches again to the left. The main stem has a syzygy at the second joint. The third branch on the left has syzygies at the second, third, twenty-first, twenty-fifth, and thirty-sixth joints; it has apparently sixty-eight joints, and seems to be perfect.

The main stem branches again to the left at the eleventh joint. It has syzygies at the third and seventh joints. The fourth branch on the left

has syzygies at the first, third, and fifth joints. There are only eleven joints of this arm preserved, and five of the stem beyond this.

In the left arm of Plate IV. Fig. 1, the eighth joint is the axillary of the first fork to the right. The first, fourth, and sixth joints have syzygies. The first pinnule is on the third joint. The second pinnule is on the epizygial of the fourth joint. The third pinnule is on the epizygial of the fifth joint. The fourth pinnule is on the epizygial of the sixth joint. Of the first branch on the right only forty-two joints are preserved. It has syzygies on the second, third, and thirteenth joints. At the seventh joint the main stem branches again on the left; the third joint has a syzygy. Only two joints of the left branch are preserved. The main stem branches again to the right on the seventh joint; the second joint has a syzygy. Only three joints of this branch are preserved.

The main stem branches again to the left on the ninth joint. The third and seventh joints have syzygies. Only three joints of the main stem and only three of the branch remain.

The arm on the right in Plate IV. Fig. 1, has syzygies on the first and second joints. The first pinnule is on the third joint. The fifth joint has a syzygy, and also the sixth. The arm branches on the eighth joint. The second pinnule is on the right, and is on the epizygial of the fourth joint; the third pinnule is on the epizygial of the fifth joint, and the fourth on that of the sixth.

Seen in profile, the arm joints of the branches are deeply indented for the insertion of the base of the pinnule; the lower joint, the pinnule of which is on the other side, having a longer face than the upper one, projects, when seen in profile, into a triangular point with rounded ends formed from its junction with the trapezoidal outline of the lower face (Plate I. Figs. 1, 7).

Seen from above, the lines of joints of the lower brachials are more or less parallel (Plate III. Figs. 1, 2), while the alternating long and short sides of succeeding brachials become more and more prominent, as well as more and more regular, as we pass from the first axillary along the main stem, and to each of the branches towards the extremity of the arm.

The position of the first pinnule in genera allied to Calamocrinus seems to be very variable. In Hyocrinus it is the third brachial; in Bathycrinus the third brachial is the first axillary; in Rhizocrinus the first pinnule is on the third or fourth brachial; that is, if we regard as a single joint

adjoining brachials united by syzygies or trifascial articulations, and carrying no pinnules; while if we consider a brachial to be represented by each face, the first pinnule appears on the sixth arm joint in Hyocrinus, the first axillary on the third in Bathycrinus, and the first pinnule on the eighth in Rhizocrinus and on the fourth in Calamocrinus.

While in Metacrinus the first pinnule is on the second brachial or the third joint, the first axillary in almost all Neocrinoids is, according to Carpenter, the third brachial, with the exception of Metacrinus.* To this we must add Calamocrinus, which differs from Apiocrinus and Millericrinus in having so many radials before the first axillary. It however resembles Metacrinus in having several radials, with a syzygy in the second radial.† In Guettardicrinus, Apiocrinus, Millericrinus, and Encrinus, the arms branch at the third radial, while in Bourgueticrinus and Rhizocrinus there are five simple arms.

As has been noticed by previous writers, the joints which carry pinnules really resemble abnormal axillaries; so that if we attempt to use the presence of an axillary at the third brachial as one of the distinguishing features of Neocrinoids when compared to Palæocrinoids, as has been done by Carpenter, we shall find that there are quite a number of exceptions to the rule. The close resemblance of the joint bearing the first pinnule in Calamocrinus to an axillary is well seen in Plate III. Fig. 6, showing the outline of that side of the joint (the third brachial) to which the first pinnule, $pn'$, is inserted. See also Plate III. Fig. 8, showing the second pinnule, $pn''$, inserted to the epizygial of the fourth brachial, which has all the appearance also of an axillary.

A still more striking illustration of the same point is shown in a somewhat magnified figure of the skeleton of the lower part of an arm seen from the interior (Plate XX. Fig. 2), which shows the base of attachment of the first pinnule, $pn'$, to the third brachial, and that of the second pinnule to the fifth brachial.

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* While, as has been stated by Carpenter of Neocrinoids with divided rays, in the greater number the third primary radial is the axillary, in Palæozoic Crinoids this is not fixed, and the first radial may be the axillary, and its position is the only distinguishing character of importance between some Palæozoic genera and Encrinus.

† In Metacrinus angulatus (Chall. Rep., Plate XXXIX. Fig. 1) the third and fourth radials have pinnules, the fifth being the axillary. In Metacrinus nodosus (Chall. Rep., Plate L. Fig. 1) there are eight radials with syzygies on the second, third, sixth, and seventh joints, all of which have pinnules except the first and sixth. As Carpenter has remarked (Chall. Rep., p. 52), the position of the brachial syzygies is by no means constant, though of some value among the Comatulæ for systematic purposes.

Hall figures in the Twenty-fourth Annual Report (1872) of the State Museum of Natural History of New York, Plate V. Fig. 14, a portion of an arm bearing pinnules, in which the joint carrying the pinnules may justly be considered an axillary; yet it is only a one-sided joint, as in the case of the joint (the modified axillary) for the first pinnule of Calamocrinus.

## ARM JOINTS.

The arm joints are remarkable for the great size of the muscular fossæ, and the expansion of the fossa for the dorsal ligament. The transverse ridges separating the muscular fossæ from the fossa for the dorsal ligament vary greatly in direction and in shape. Sometimes it is a straight ridge running obliquely across the joint (Plate XIV. Fig. 4). In other cases the ridge on the two sides of the axial canal runs off at a different angle (Plate XIV. fig. 2), or one shank of the ridge is slightly curved (Plate XIV. Fig. 9, Plate XV. Fig. 2), either convex or concave. Or it forms a slightly curved arch, concave towards the dorsal side, for the reception of the dorsal ligament (Plate XIII. Figs. 11, 14, Plate XIV. Figs. 8, 10, Plate XV. Fig. 5).

The arm joints are never symmetrical, one side or the other being universally the largest (Plate XIII. Figs. 11–14, Plate XIV. Figs. 2–5, 8–10, Plate XV. Figs. 1–5), and the largest side is not uniformly the one in which the symmetry is disturbed by the cavity for the insertion of the pinnule (Plate XIII. Figs. 13, 14, Plate XIV. Fig. 3, Plate XV. Fig. 5); though such is the case in Plate XIV. Fig. 8 and Plate XV. Fig. 4.

The transverse ridge may be more or less flat; sometimes it is quite broad with very indistinctly rounded edges (Plate XIII. Fig. 11), or comparatively narrow with sharp edges (Plate XIV. figs. 3, 4, 9), or quite indistinct towards the edges (Plate XIII. Fig. 14, Plate XIV. Fig. 10). The reticulation of the fossæ is quite compact, presenting on the surface a delicately pitted appearance. (See Plates XIII., XIV., and XV.) The reticulation is somewhat coarser near the transverse ridges, and also towards the ventral surface of the joints. The syzygial faces are usually more uniformly pitted (Plate XIII. Fig. 12, Plate XIV. Fig. 5, Plate XV. Figs. 1, 3), and show a radial arrangement of the cells on the periphery of the joints, generally more marked than the similar radiating lines extending in some of the fossæ from the outer edge inward (Plate XIII. Figs. 11, 13, Plate XIV. Figs. 2, 4, 10, 12, Plate XV. Figs. 4, 9, 11, 12). On the outside surface of the arm

joints the reticulation appears quite coarse (Plate XIII. Fig. 15). See also the coarse reticulation of the surface of the axillary in Plate XV. Figs. 6, 7.

The distal faces of the axillary are greatly modified by the presence of a sharp keel (Plate XV. Figs. 6–9) which separates its right and left faces, the proximal faces of the first joint of the fork and of the arm fitting against the distal faces of the axillary, having only one muscular fossa and one for the dorsal ligament (Plate XV. figs. 9, 12), the other muscular fossa being atrophied. In the case of the second axillary, the distal face (Plate XIV. Fig. 12) shows the condition of the muscular fossæ of the left and right joints.

The keel of the second axillary projects like a thin, short dagger-shaped lamella between the first joints of the fork and of the main arm (Plate XIV. Fig. 12); it appears, when seen from the ventral side, as reduced to a mere ridge extending from the centre of the upper triangular point of the axillary to the centre of the lower face (Plate XIV. Fig. 11).

The young arm joints near the extremity of the arms differ entirely in their structure from the older joints with their complicated sutural joints, broad lateral processes, and high dorsal part of the arm joint, and the insertion pit for the pinnule. An arm joint, the fifth from the end of the arm (Plate XII. Fig. 8), still shows plainly the simple original reticulation arranged in radiating lines towards the articulating faces, and forming an open network of large irregularly shaped cells. Some of the shanks of the newly formed cells remain as large curved spines on the anterior extremity of the dorsal part of the arm joint. A slightly older joint (Plate XII. Fig. 9) shows a greater extent of the closer radiating reticulation adjoining the sutures of the joints. In this joint the axial canal is formed by the bridging over of the concave floor of the ventral side of the joint by spurs running out laterally from the large cells in the central part of the arm joint, until they meet from opposite sides and form a thin floor of large-meshed cells enclosing the continuation of the axial canal (Plate XII. Fig. 10). A profile view of a still younger joint shows it to be merely a curved sheet of open-work limestone reticulation (Plate XII. Fig. 11), and the end view shows how rudimentary are still the sutural faces of the joint (Plate XII. Fig. 12), although there is already a marked indication of the difference in size so prominent in the older arm joints between the opposite sides of the joints enclosing the axial canal. The axial canal occupies a comparatively large space in the sutural face of the arm joint.

The syzygial sutures are already in the young stages recognizable as such, and present marked differences in the outlines with the sutures which are to be muscular sutures. Compare the young syzygy, Plate XII. Fig. 17, with the other young joints figured in Plate XII. Figs. 15, 16. A terminal arm joint is figured in Plate XII. Fig. 13; it presents as yet no indication of forking to form the pinnule; but from its length it is probable that some of the larger shanks of the terminal cells will soon develop more rapidly than the rest, and that a new joint will then be formed with a rudimentary articulation such as is figured on Plate XII. Figs. 15, 16. The last two joints of Figure 14 of the same plate carry no pinnules, so that one of the newly formed sutures will probably be a syzygy.

## PINNULES.

There is a very marked difference in the aspect of the pinnules of different parts of the arms. Those pinnules which are below the axillary, the greater part of which, or the base at least, is closely connected with the perisome, are characterized by the great solidity and shortness of the joints, and the powerful wing-like expansions of the lower part of the joints (Plate XVI. Fig. 1). Those on the main branch of the stem, from the first axillary to the last, are somewhat longer, with more elongated joints, and the wings at the base of the joints narrower and more distinctly separated (Plate XVI. Figs. 2, 3, 5). Those of the forks and of the extremity of the arm are marked by a gradual decrease in the size of the wings, until they become, like the pinnules near the end of the main arm (Plate XVI. Fig. 4), rather slender, with but slight lateral projections at the base of each joint.

The distal pinnule joints resemble in their structure that of the younger arm joints before they have developed their characteristic sutural faces, with the exception that on the ventral edge of the pinnule joints towards the base there develops on either side, or one side alone, a sort of buttress-like wing, which becomes stronger as we approach the basal joints of the pinnule. See Plate XVI. Figs. 6-13. with corresponding views of the young arm joints figured in Plate XIII. Figs 3-9. The arrangement of the reticulation of the ventral surface beyond the floor forming the axial canal in radiating lines is, however. usually more marked in pinnule joints than in arm joints (compare Plate XVI. Fig. 8. with Plate XII. Figs. 8, 11); although in other arm joints (Plate XIII. Figs. 4-6) the arrangement of the reticulation in

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radiating lines is fully as prominent as in the pinnule joints in Plate XVI. Figs. 8, 12. With the exception of the lower stout pinnule joints of those which are placed near the base of the arms adjoining the calyx, they have no distinct articulating face. There is a broad ridge with rounded edge, through which passes the axial canal of the pinnule, and which corresponds in a general way to the transverse ridge separating the dorsal ligament from the muscular fossæ. But there are no well defined fossæ, the ridge forming with the adjacent joint a sort of rudimentary ball and socket joint (Plate XIII. Fig. 1), while in more distal pinnule joints the articulating faces are nearly flat surfaces (Plate XIII. Fig. 2, and Plate XVI. Fig. 7), even, as in the last case, where the buttresses of the sides of the pinnules have undergone considerable development.

The development of the lateral wings of the pinnule joints appears to be quite irregular, especially in those pinnules which are near the base of the arms attached more or less to the surface of the disk, the size of the wing depending greatly upon the freedom for expansion which it meets; so that it is not an uncommon feature to find the wing of one side greatly developed while that of the other is quite narrow or absent. Compare Plate XVI. Figs. 6, 9–13. The reticulation of the limestone meshwork of the pinnule joint is comparatively coarse, much as is the case with the reticulation of young arm joints. See Plate XVI. Figs. 14–17.

According to the position of the pinnule joint, the degree of development of its lateral wings, and the number of its dorsal spines, the articulating face varies between that given in Plate XVI. Fig. 7, and that figured in Plate XIII. Fig. 2.

As has been noted before, the arrangement of the primary pinnules of Calamocrinus is somewhat different from that of the majority of Crinoids, which have the third radial an axillary, and in which the joint preceding the axillary bears no pinnule.* There is of course no pinnule at the axillary, and the first joint after the axillary carries no pinnule, as in the majority of the Comatulæ and some species of Pentacrinus.

We note the same differences in the lowest pinnules of Calamocrinus which characterize those of the Comatulæ, of Pentacrinus and Metacrinus; their basal joints are ornamented with spurs and keels, and the shape of the joint is rectangular.

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* In Metacrinus there is a pinnule below the axillary. Chall. Rep., Plate XXXVIII., and Plate XLIII. Fig. 2.

In Calamocrinus. as in other Neocrinoids except Hyocrinus, the pinnules are small compared with the arm of which they form a part. In Hyocrinus, as noted by Carpenter, the pinnule-bearing joints have rather the appearance of axillaries (Chall. Rep.. Plate VI. Figs. 1–3), and resemble the axillary of the end of an arm of P. decorus (Chall. Rep., Plate XXXV. Fig. 1). The axillary which bears the last pinnule and the continuation of the arm can scarcely be distinguished except by the greater length of the joints.

Carpenter has called attention to the axillary appearance of the pinnule-bearing joints in Rhizocrinus (Chall. Rep., Plate IX. Figs. 4. 5) and in Hyocrinus (Chall. Rep., Plate VI. Figs. 1, 2); and hence it is natural that an axillary. "conceding the fundamental identity of the arms and pinnules," should not give rise to arms and a pinnule also (Chall. Rep., p. 60).

In Calamocrinus the joints next the radials are syzygial. In Rhizocrinus lofotensis the first pinnule is on the eighth brachial, and in R. Rawsoni on the sixth (Chall. Rep., p. 47). In Atelecrinus there are no pinnules until the twelfth brachial.

Bearing in mind the generally received identity of an arm and a pinnule, it is difficult to understand the position taken by Walther.* According to him, there are no less than five primary embryonic pinnules (tentacles), ten secondary, and ten tertiary ones, before the arms begin to form. Such is also the case in the young Starfishes, young Echini, and young Ophiurans; there are three pairs of tentacles and an odd one before we may say that the ambulacral tube and its arms begin to form. But there is nothing to show that the five primary pinnules (tentacles) develop into the regular pinnules, and I cannot understand the figures of Walther in Plate XXVI. Figs. 3ª, 3ᵇ. What is the first plate at the base of his pinnules unless it be a radial? He suggests that the pinnules are not branches of the arms, but that the arms must be considered as carriers of the pinnules; that the early Crinoids had pinnules and no arms, and that the arms only originated in the course of palæontological development; and that we can in no wise regard the pinnules as modified arms; and he gives various other physiological reasons which are in direct contradiction with the observations of the most careful investigators of Crinoids. If there is one pinnule only on a joint, what becomes of the fossil genera in which there are two? He thinks he has discovered in the hook-like joint of the axillary the

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* Walther, Johannes, Untersuchungen über den Bau der Crinoiden. Palæontog, XXXII, 1886. p. 155.

remnant of a primordial pinnule in the fossil Antedon pinnatus, and that
this hook is separated from the joint by a suture. The proof of the ex-
istence of the so called primary pinnule can hardly be based upon the
indistinct figure he gives in Plate XXVI. Fig. 10$^g$. The same may be
said of its discovery in Solanocrinus gracilis from Kelheim (Plate XXV.
Fig. 2$^a$); and we cannot of course agree with him in also considering the
knobs of the axillaries of the genera which he figures in Plate XXIV.
Figs. 2$^a$–2$^g$, as the base of the first pinnule. The arm begins according
to him with this first pinnule.

## SIDE PLATES AND COVERING PLATES.

The food groove of the ventral disk is protected laterally by a series of
plates arranged irregularly in a vertical plane. The base of these plates
either abuts directly against the inner rows of the perforated perisomatic
plates (Plate II. Fig. 3, Plate III. Fig. 2, Plate V. Figs. 1, 4, Plate VI. Figs.
1, 4, 5); or there are, especially near their junction with the oral plates
at about a third of the distance from the oral plates to the branch of the
food groove leading to the nearest pinnule, a number of irregularly shaped
protuberances or digitiform masses which separate these so called side plates
from the perforated plates of the perisome (Plate VI. Figs. 1, 2, Plate IX.
Fig. 1).

On being boiled with potash, the limestone plates forming these digiti-
form masses are found to be irregularly shaped polygonal, flattened, or
more or less cylindrical bodies (Plate X. Figs. 1–7). Some of them are
nearly smooth (Plate X. Fig. 1), others somewhat spiny (Plate X. Figs. 2–4),
and others again in the shape of spines (Plate X. Figs. 5–7). The reticu-
lation of the main body of these plates does not differ from that of other
plates; it is more or less polygonal, but closer than that of the side plates
themselves (Plate X. Fig. 8). Towards the first branch of the food groove
of the disk the side plates become more prominently vertically arranged,
assuming the shape of lamellæ with edges more or less lobed or spiny (Plate
V. Figs. 1, 4, Plate VI. Fig. 1), on the upper edge of which ride small
covering plates, which when pressed together close the food groove (Plate
V. Fig. 1. Plate VI. Figs. 1, 3–6). These lamellar side plates sometimes
extend well along the food groove of the arms as far as the third fork
(Plate VII. Fig. 13). The side and covering plates of the food groove of

the main stem of the arm are quite irregular in their appearance, which depends greatly upon the thickness of the cutis which conceals the calcareous plates forming the skeleton of the side or covering plates (Plate VII. Figs. 1, 2, 17, and Plate VIII. Fig. 11). Near the base of the food groove of the arm, close to its junction with the disk food groove, the covering plates are most irregular in outline (Plate VII. Figs. 1, 2), but when pressed together form an irregular pavement completely closing it. Some of these covering plates are more or less spiny. The side plates themselves are most irregular in shape, and are either digitiform plates, like those of Plate X. Figs. 1–5, or lamelliform, like those of Plate VII. Figs. 3, 13, having in addition comparatively large lateral spines, as seen in Plate VII. Figs. 1, 2.

As we pass from the base of the arm towards the extremity, both the side and the covering plates become more regular in shape, until we have one or two lateral plates supporting a single covering plate. The passage from the irregular plating formed by the covering plates at the base of the arms into a regular alternating arrangement is often quite sudden, and in the same parts of adjoining arms the covering and side plates appear very differently developed. Compare, for instance, the condition of these plates in Plate VII. Fig. 9, and Plate VIII. Fig. 1, or Plate VII. Fig. 14. In general, however, the succession represented in Plate VII. Fig. 1, Plate VII. Figs. 4, 5, Plate VII. Figs. 6, 7, Plate VII. Figs. 10, 11, 12, Plate VII. Figs. 15, 16, shows the gradual passage of the lateral and covering plates, first forming a wall of irregular side plates supporting irregular covering plates, to side plates and covering plates which lose gradually their varying outlines and projecting spines, and become little by little side plates of regular shape, with spines passing into knobs or disappearing entirely, and covering plates alternating with the greatest regularity and forming a beautiful plating of triangular reticulated network. See Plate VIII. Figs. 1–5.

The stoutness of the side and covering plates diminishes rapidly as we pass from the disk or from the base of the arms towards their extremity. Those of the disk and proximal part of the arms are comparatively stout, often thicker and more solid than the adjoining perforated perisomatic plates; and the side plates especially are greatly strengthened by vertical ribs or by lateral spines, even after the covering plates have become comparatively attenuated and consist of a very open meshwork limestone, with circular or elliptical meshes and huge projecting terminal spokes (Plate VIII. Figs. 2–4).

The reticulation of the side plates is at first quite regular, made up of circular or elliptical meshes (Plate XII. Figs. 3, 6), the walls separating the meshes varying greatly in width and thickness. As the side plates increase in size and thickness, the regular reticulation becomes more or less obscured by the formation of a second, or even a third or fourth, floor of calcareous meshwork. The secondary meshwork thus formed is very irregular in out-line, the walls separating adjoining cells running in all directions, becoming frequently anchylosed with vertical or horizontal rods uniting together a series of cells on different planes. Figure 5 of Plate XII. shows one of the side plates in which the secondary reticulation has been formed principally at the upper end, the remaining part of the side plate still showing the original reticulation. In Figures 2, 4, Plate XII., the secondary reticulation has obscured the primary reticulation of nearly the whole of the side plates; and in Figure 1 there is no trace of it to be seen through the soldering of the limestone rods of the different planes of the meshwork.

In Plate XI. Fig. 1, there is a tendency to anchylosis of the adjoining cells, and the first appearance on one side of the side plate of the secondary reticulation to form lateral spines, such as have been figured in Plate VII. Fig. 1. An enlarged view of this secondary reticulation is shown in Plate XI. Fig. 5, forming the base of a lateral spine of a side plate, and Figures 6, 7, of Plate XI. show two of the lateral spines of a side plate in different stages of development. The reticulation of the side plates of Plate VIII. Fig. 1, is a combination of the conditions of the secondary reticulation found in Plate XI. Fig. 1, and Plate XII. Fig. 5.

The side and covering plates of the groove of the pinnules do not differ in their arrangement from that of the arms. Their shape and structure presents about as great variation in the pinnules found near the base of the arms and those near the middle or extremity of the arms and forks as do the corresponding parts of the arms. We find the same lateral processes of the side and covering plates in pinnules close to the disk (Plate VIII. Figs. 8, 9) which we find in the covering and side plates of the food groove near the base of the arm. As we pass to pinnules nearer the ex-tremity of the arm, the covering and side plates become more simple (Plate VIII. Fig. 10). The original elliptical reticulation of the side plates is grad-ually obscured in the side plates of the groove of the pinnules, as it is in the side plates of the arm food groove (Plate XI. fig. 10).

The reticulation of the irregularly shaped covering plates of the food

groove of the arms near their base adjoining the disk is close and indistinct, similar to that of the corresponding side plates (Plate X. Figs. 1–5). As we proceed toward the extremity of the arms, the original elliptical groundwork becomes more apparent (Plate VII. Fig. 9, Plate VIII. Fig. 1), and the covering plates assume a more triangular outline, with a slightly re-entering base and rounded apex. The original elliptical reticulation forms the network of the base of the covering plates, and from this radiate spokes connected laterally by transverse rods forming rectangular or irregularly shaped cells of considerable size compared with those of the base of the covering plates (Plate VII. Fig. 9, Plate VIII. Figs. 2–5, Plate XI. Fig. 2), the radiating spokes often projecting far beyond the outline of the covering plates. See also Plate XI. Figs. 8, 9, Plate XII. Fig. 7.

The covering plates are also frequently surmounted with spines (Plate VII. Figs. 1, 2, 5). These spines are formed like the lateral spines of the side plates by the formation of a secondary reticulation. These spines may be at the surface of the covering plate or on the fan-shaped extremity (Plate XI. Fig. 2); or they may be lateral spines of the wing-like projections formed at the base of the covering plates (Plate X. Fig. 9), which form a sort of saddle (Plate X. Figs. 9, 11) by which it is roughly articulated to the adjoining side plates. This saddle-like process and its formation are well shown in the structure of some of the covering plates from pinnules taken near the base and the middle of the arm. Figure 11 of Plate XI. is a covering plate seen from above, showing its regular original elliptical reticulation; Figure 12 shows a similar covering plate from the inside, with the beginning of the secondary reticulation which is to form the spurs to articulate with the adjacent side plates; Figure 13 is a side view of one of the covering plates showing the wings or spurs connecting it with the adjacent side plates; and Figure 3 is one of the covering plates of a pinnule, with a large open irregular reticulation at the extremity.

The mode of formation of the spurs and wings connecting the covering plates to the side plates is perhaps best seen in the figures of a covering plate taken from the groove of a pinnule close to the base of the arms. Figures 9 and 10 of Plate X. are the extremity and the saddle-like base of one of the covering plates. The secondary reticulation, to increase the thickness of the plate, or to form spines, has begun to form at the base of the spines (Plate X. Fig. 9) and on the sides of the extremity (Plate X. Fig. 10); otherwise the original reticulation is still quite distinct. In Fig-

ure 11 of Plate X., showing the base of another covering plate, the articu-
lating spurs are very prominent laterally, and from the base of the covering
plate a broad fan-like projection of open meshwork juts out beyond the
general outline. The mode of formation of the secondary reticulation from
Figures 9 and 11 of Plate X. is shown in Figure 12 of the same plate.

Carpenter in his Challenger Report speaks of the great variety in the
covering and side plates of Pentacrinus. In Pentacrinus naresianus the
covering plates and side plates are fused, and form a long plate. They
are differentiated again in P. Blakei. Carpenter also calls attention to the
fact that in Metacrinus the side plates and covering plates are generally
better differentiated than in Pentacrinus. In Hyocrinus there are no side
plates on the arms, yet they are well developed on the enlarged parts of the
pinnules containing the genital glands (Chall. Rep., Plate V c, Fig. 10, sp).

Wachsmuth and Springer have mentioned * the existence of a small row
of side pieces on each side of the two rows of robust covering pieces in
Megistocrinus nobilis, W. & S.


## INTERRADIAL PLATES.

With the exception of Hyocrinus, none of the Stalked Crinoids discovered
by the recent deep-sea dredging expeditions possessed large distinct peri-
somic plates between the peristome and the edge of the cup. The presence
of a heavy interradial plating in Calamocrinus, similar in all respects to that
of Apiocrinus and Millericrinus, is an important structural feature hitherto
unknown in any recent Stalked Crinoid. The figures of Plates II. to VI.
nearly all illustrate some structural point of this interradial plating.

The perisomic plating consists of two kinds of plates. One set, arranged
in from seven to eight irregular rows, the lower row resting directly upon
the upper faces of the radials, is made up of thick, irregularly shaped,
generally hexagonal plates, closely joined together by their apposed edges
so as to form a stout arch between the lower part of adjacent arms. These
plates are imperforate and closely soldered to the edges of the arm joints,
which throw out small wing-like appendages closely intercalated with the
perisomic plates, and forming a solid, practically rigid calyx as far as the
fourth or fifth joint of the second pinnule (Plates II., III., Plate IV. Figs.
9–14, Plate V. Figs. 1, 2, 4, Plate VI. Fig. 5).

* Geol. Survey of Illinois, Vol. VIII. p. 171, 1890.

The second set is made up of smaller plates extending from the lateral plates of the food groove round the peristome towards the imperforated plates. These smaller plates are somewhat thinner, perforated, and arranged in from four to six irregular rows. Figure 1 of Plate VI. gives a general view of the arrangement of the perisomic plates seen facing the mouth.

The small plates in the anal interradium are not perforated (Plate II. Figs. 2, 4, Plate III. Fig. 5, Plate V. Figs. 2, 3, Plate VI. Fig. 1). In Plate II. Figs. 1, 3, Plate III. Figs. 1, 2, Plate V. Figs. 1, 4, and Plate VI. Fig. 5, the relation of the perforate to the imperforate plates is shown for different interradial spaces.*.

There is apparently little regularity in the arrangement and size of this perisomic plating. Even the lower rows of larger imperforate plates adjoining the upper faces of the radials differ not only in different specimens, but in different interradii of the same specimen. Compare Plate II. Figs. 1, 3, 5-13, Plate III. Figs. 1, 2, and Plate V. Fig. 1.

The lower rows of large imperforate plates abutting upon the radials are in no wise to be distinguished from similar plates figured by D'Orbigny and de Loriol for Apiocrinus and Millericrinus. They unite the adjacent arms into a rigid calyx; and an examination of the figures of some of these imperforate plates (Plate IV. Figs. 9-14) shows that they are fully as solid and compact as the so called calyx interradials of the Apiocrinidæ proper.

It is true that they occupy in some cases among the fossil Apiocrinidæ a somewhat different interradial position from that which they hold in Calamocrinus, in the former cases filling only a comparatively small space left between adjoining arms. But their mode of junction, either with the arm joints, or with the joints of the pinnules, or with the upper faces of the radials, is such as to make a complete and firmly united mail of plates, and to form with the calyx a large rigid cup, expanding in width gradually from the dorsal face of the basals and the lower parts of the arms nearly to the first axillary.†

The wing-like projections from the sides of the arm joints uniting them

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* Perrier states (Organisation et Développement de la Comatule de la Méditerranée, Nouv. Arch. du Museum, IX. 2e Série, 1866) that the water pores are wanting in the anal interambulacral area of Actinometra (p 101), while they are found over the whole disk of Pentacrinus and Antedon.

In Hyocrinus the anambulacral plates are perforated by water pores, but not in the anal interradium.

† The ventral disk and arms both in Antedon and Actinometra are devoid of continuous plating (Carpenter, Chall. Rep.), yet it may be strongly developed between the lower division of the rays extending up to the level of the third axillary.

with the interradial plates are shown in Plate II. figs. 1, 2, Plate III. Figs.
1, 2, 5, Plate V. Figs. 1, 2, and Plate VI. Fig. 5. The same figures, and
Plate III. Fig. 4, Plate V. Fig. 4, and Plate VI. Figs. 4, 7, show the con-
nection of the same plates with the first, second, and third pinnules. The
thickness of the vault formed by these imperforate interradial plates is
shown in Plate III. Figs. 5, 6, 10, and Plate VI. Fig. 7. In the profile
figure of the lower brachials below the second pinnule (Plate III. Fig. 5),
the thickness of the wings of the arm joints is seen in section to their
junction with the upper face of the radials. It is to these faces that the
perisomic plates are firmly united. See also Figures 6–9 of Plate III. In
Figures 6, 7, we have the edge of the vault of the perisomic plates extend-
ing from the radial to the first pinnule; in Figure 8, to above the second
pinnule. The lower part of Figure 7 of Plate V. shows the plating above
the radial to the first pinnule of the lower part of an arm corresponding
to Figure 5 of Plate III.; the plating however conceals the inner parts of
the arm joints shown in Figure 5. In Figure 7 of Plate IV. we see the
plating in profile above the base of the first pinnule. Seen from the in-
terior, the connecting tissue conceals the outline of the imperforate plates,
and they appear more or less elliptical (Plate IV. Figs. 3–6). The outline
of the imperforate plates is completely concealed (Plate IV. Fig. 3) when
the upper part of the vault is seen from the inside.

The sutures of the imperforate plates are very marked, while those of
the perforated plates are more or less indistinct, from the number of pores,
granules, and other irregularities of their surface, (Plate II. Figs. 1, 3, Plate
III. Figs. 1, 2, Plate V. Figs. 1, 4, Plate VI. Figs. 1, 4,) which become more
dense as they approach the food furrow. The spongy character of the
perforated plates is seen in Plate IV. Fig. 8.

The interradial plates merely abut against one another by their thick
edges; they are held together by the thickening of the skin over the joints,
both on the inner and outer surfaces of the calyx. The inner surface is
comparatively thickest, that of the outer surface being reduced to a mere
connecting film, the thick interradial plates having resorbed nearly the
whole of the perisomic skin, which in such genera as the modern Penta-
crinus forms the connective tissue in which the smaller disconnected plates
of the perisome are sunk, and form the indistinct pavement of the ventral
surface.

The interradial plates of Calamocrinus are fully as stout and rigid as

those of many of the Camerata; and the passage of the interradials to small ventral plates in several palæozoic genera corresponds to the structure of the perisome in Calamocrinus.

The interradial plates of Taxocrinus intermedius (Geol. Survey of Illinois, VIII. 199) can, according to Wachsmuth and Springer, be traced in both the specimens they describe to the ventral side, the plates of the third row forming a sharply defined edge, against which the plates of the ventral covering rest.

The junction of the perforate and imperforate perisomatic plates is shown in Plate IX. Fig. 2, which represents some of the smaller perforated plates close to the side plates adjoining the food groove near the central part of the disk. As is seen in Plate IX. Fig. 2, the number of pores to each plate varies greatly; sometimes the pores are merely openings in the coarser reticulation (Plate IX. Fig. 4, *p*), or there seems to be a discontinuity in the limestone meshwork, leaving large irregularly lobed openings, as in Plate IX. Fig. 3, *p*. In the plates close to the food groove the reticulation becomes somewhat indistinct, and more or less lamellar in structure, giving the surface of the perforated plates a spongy appearance, as in Plate IX. Fig. 5, *p*. A transverse section across one of the perforated plates shows that the canals into which these pores of the surface of the plates open are more or less curved, and form broad irregular canals in the meshwork of the plate, passing either completely through or terminating in a cul-de-sac (Plate IX. Fig. 6, *p*). The reticulation of the perforated plates is also somewhat coarser than that of the imperforated plates, especially those of the lower rows near their junction with the radials.

The plates pierced for pores pass in Calamocrinus very gradually into the so called interradials; this plating is very highly developed in Extracrinus and in Apiocrinus (de Loriol); and they apparently (Von Koenen) do not differ in any way from the ventral disk of the Ichthyocrinidæ, with which Wachsmuth. however, said originally that "they cannot in the remotest degree be homologized";* but he and Springer have since come to a different conclusion.

The water pores are very numerous in some species of Pentacrinus. They are well figured by Müller for P. asterius. and by Carpenter for P. Wyville-Thomsoni. who mentions them in P. Milleri and P. decorus. The angles forming the junction of the food grooves round the mouth

opening come closely together in P. naresianus and in P. decorus. In the former the plates round the mouth are larger, and they entirely conceal the opening; while in other species there is a broad bare area, forming eight to ten or more angles bounded by small plates. There are no pores drawn in the anal interradium of P. Wyville-Thomsoni, as in Calamocrinus. The continuation of the perisomic plates along the arms is best defined in P. naresianus.

The lower rows of plates of the anal interradium are similar to those of the other interradii; but they rapidly pass into longer and larger plates, which again diminish rapidly in size towards the extremity of the anal proboscis (Plate II. Figs. 1, 2, 4, Plate III. Fig. 5, Plate V. Figs. 2, 3, Plate VI. Fig. 1), and around the small anal opening they are stout plates becoming almost papillæ, but all imperforate.

The interradial plates protecting the anal proboscis seem to differ as much in size and shape in the different specimens as the interradial plates of the rest of the calyx; in one case they are much smaller and more numerous in proportion to the size of the anal proboscis (Plate III. Fig. 3) than in the anal proboscis figured in Plate II. Figs. 2, 4.

The anal proboscis in all the specimens is placed close to the oral aperture. The anal proboscis was evidently capable of but slight movement, being for more than half its length rigidly soldered to the edge of the adjacent arm and pinnule joints (Plate II. Figs. 2, 3, Plate III. Fig. 3, Plate V. Figs. 2, 3, Plate VI. Fig. 1). The upper third alone was capable of a certain amount of lateral and of vertical movement. The anal proboscis of the specimen shown in Figure 3 of Plate III. was proportionally longer than those of Plate VI. Fig. 1, and Plates II. and III.

It is interesting to compare the descriptions by D'Orbigny and de Loriol of the interradials of the fossil Apiocrinidæ; for in some of the species of the genera Guettardicrinus and Apiocrinus the presence of stout interradials and their close union with the rays, which tend to increase the size of the cup, present many points of resemblance to the Tessellates.

In Guettardicrinus, Apiocrinus, Uintacrinus, and Calamocrinus, the interradials extend beyond the axillaries. The arms of Guettardicrinus are united as far as the second brachial, either directly or by interradials. In Apiocrinus Parkinsoni the second and third radials are in close contact.

Interradial plates, the *pièces accessoires* of D'Orbigny,* have been figured and described by him in Guettardicrinus dilatatus (Plate I. Figs. 2, 3). There are two such plates uniting the second and third radials laterally, and separated by the first and second brachials of adjoining arms from a small third interradial plate.

In Apiocrinus Roissyanus, D'Orb., the interradials are not disconnected, but form an irregular pavement of stout plates, gradually becoming smaller towards the perisome (see D'Orb., Plate III. Figs. 2, 7, 8, Plate IV. Fig. 1). The plate in the angle of the ventral edges of the adjoining first radials which connects the second radials laterally is larger than the others; it is followed by a row of two plates, then three, then five; how many there are beyond is not clear from D'Orbigny's figure.

In Apiocrinus Parkinsoni, D'Orbigny figures a small interradial in the angle between adjoining axillaries (Plate V. Fig. 2). In Apiocrinus Murchisonianus (D'Orb., Plate VI. Figs. 1, 2, 5) he figures two interradial plates, the lowest of which is in the angle of adjoining first radials.

The great thickness of the pieces composing the calyx is a marked feature of Apiocrinus and the older fossil Apiocrinidæ. The interradial pieces are equally solid, as is well shown in the ring of the second radials of Apiocrinus Roissyanus figured by D'Orbigny in his Plate III. Fig. 7. Between the second radials the interradials are fitted with all the solidity of any of the calyx pieces proper. These lower interradial pieces, both in this species and in Guettardicrinus dilatatus, are as much a part of the calyx as the first and second radials themselves, with which they are connected by the same kind of suture which unites the pieces of the calyx proper (see also Figure 6 of Plate III. of the same Memoir).

De Loriol has figured two interradial plates in Apiocrinus Meriani (Mon. des Crinoïdes de la Suisse, Plate II. Fig. 1, and Plate III. Fig. 2, Mém. de la Soc. Paléont. Suisse, IV.); they separate the second radials and rest upon the first radials; the radials are bevelled to receive them also (Pal. Franç., XI., Plate 39, Fig. I, 1ª; Plate 40, Fig. 1).

The figures given by de Loriol of Guettardicrinus dilatatus † (Pal. Franç., XI., Plates 22, 23) show a somewhat different arrangement of the inter-

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* Hist. Nat. des Crinoïdes.

† De Loriol says also that Guettardicrinus dilatatus is the only species of the genus characterized by radials of the second order, forming a part of the walls of the cavity of the calyx, with numerous interradial pieces not mentioned by D'Orbigny.

radial plates from that given by D'Orbigny[*] of the same species. They
form a continuous pavement of stout plates. intercalated between the ra-
dials and extending to the third brachial, arranged in two rows and closely
fitted between the plates they unite.

De Loriol also shows that the interradials of Apiocrinus Parkinsoni (Pal.
Franç., XI., Plate 30. fig. 1[b]) were perhaps arranged similarly to those of
Guettardicrinus dilatatus. While his figures of the interradials of Apio-
crinus Roissyanus (Pal. Franç.. Plates 41–45) agree essentially with those of
D'Orbigny, they are numerous and very unequally developed, varying in
number and arrangement in each interradial space. He also figures inter-
radials in Apiocrinus magnificus (Pal. Franç., Plate 48, Fig. 1, Plate 49,
Fig. 1), where they are very small; in Apiocrinus Cottaldi (Pal. Franç., Plate
48, Fig. 26), which probably possessed others also; in Apiocrinus Rathieri,
with its large interradial areas (Pal. Franç.. Plate 49, Fig. 2. Plate 50,
Figs. 1, 2, 2[a], 3); and in Apiocrinus Murchisonianus (Pal. Franç., Plate
53. Fig. 1); he also speaks of them in A. Belthemieuxi (Pal. Franç., p.
313). In the genus Millericrinus he figures interradials in M. Goldfussi
(Pal. Franç., Plate 93. Figs. 1[a], 1[b]); in all of which the interradials are
characterized by their massive structure and their close fitting to the
adjoining radials or brachials, forming as much a part of the calyx as
either the basals or the first radials. But there is nothing, as he says,
in spite of their massiveness and the variety found in their dimensions or
shape. to indicate any differences in the various interradial spaces such as
would denote an anal area, as in Palæocrinoids.

The series of interradials in the fossil Apiocrinidæ usually begins with
a single plate. irregularly hexagonal. generally larger or very much larger
even than any of the other interradial plates. Sometimes, but rarely, the
second piece passes alongside of the first. They gradually diminish in size,
and, becoming smaller and smaller towards the perisome, form a vault over
the ventral surface where the plates may have only formed the support
of a thin membrane.

In speaking of the interradials of A. Parkinsoni, de Loriol states that
the interradial pieces, owing to their cuneiform shape, do not always
reach the external surface of the calyx, and thus some of the interradial
spaces may appear to have no interradial plates, others four or five.

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[*] As de Loriol suggests, the sutures of the upper interradials probably escaped D'Orbigny's atten-
tion, as de Loriol examined and figured D'Orbigny's original.

Carpenter is now of opinion that the ventral plates of the Camerata are in their essential characters nothing but more or less highly developed perisomic plates. He has long believed this about Glyptocrinus, Reteocrinus, and similar forms. Recent work on Encrinus, Apiocrinus, and Calamocrinus has led me gradually to disbelieve in any vault as a system of plates distinct from a disk. When a distinct line of covering plates marking the ambulacra is not traceable, as in E. Briareus and A. Royssianus, this is not due to the ambulacra being subtegminal, as frequently asserted. The real cause, I am convinced, is not this, but that the covering plates are not clearly differentiated from the other plates of the disk.

Carpenter also says that the vault of a Platycrinoid (Chall. Rep., p. 180) corresponds collectively to the oral, interradial, ambulacral, and anambulacral plates of Neocrinoids, and that (Chall. Rep., p. 171) the so called vault of the genus Marsupiocrinus* is really the strongly plated ventral perisome; and furthermore, that he can develop the heavy vault of the Carboniferous species from the disk of the Silurian forms by a gradual course of palæontological development, although at the same time other lines of development may be going on; and finally, that the radial dome plates of the Actinocrinidæ are to be regarded as extravagantly developed covering plates, and that the term calyx interradials should be given up.

Carpenter and Wachsmuth and Springer are now fully prepared to admit that all the plates between the rays are parts of one and the same system, whether they be massive, like the first interradials of Guettardicrinus, or delicate, as in the recent Pentacrinidæ.

As has been stated by Carpenter, in the recent Crinoids thus far described, they all with the exception of Thaumatocrinus have the first radials united so as to form a complete ring all round the calyx; but in that genus the primary radials are separated by an interradial resting upon the basals below. These calyx interradials, as they have been called, are very generally present in Palæocrinoids, and help to increase the size of the cup.

In Belemnocrinus an anal plate separates two of the radials. In Hexacrinus the same is the case. In the Mesozoic Apiocrinidæ " there are

* Schluter gives excellent figures and a good analysis of Uintacrinus (Zeitschr. d. Deutsch Geol. Ges, 1878), showing remarkably well the gradual passage of the so called large calyx interradials into comparatively small actinal plates. The same structure is repeated in the angle of each pair of arms in the interpalmar spaces, the first large plate of the latter series resting upon the first two distichals, exactly as the first plate of the interradial area rests upon adjoining first radials. The central plate, without any perforation, is surrounded by a circle of five basals and five adjoining radials, with interradials fully as large as the radials.

calyx interradials essentially similar to those of the Palæocrinoids." (Carpenter, Chall. Rep. p. 39.)

In the recent Calamocrinus the interradials do not begin by a single plate, but with two or three resting upon the upper angle of the first radials, which are truncated for their reception. These are followed by several others, more or less irregularly arranged, and together with the interradials and the two lower brachials form the immovable wall of a large cup. Up to the present time, no recent Crinoid except Calamocrinus presents this structure.

The mode of arrangement of the embryonic interradial plates of Antedon, figured by Dr. W. B. Carpenter (Plate XXXIII. Figs. 7, A, B, Trans. R. S., 1866), is very similar to that of Apiocrinus, only the plates are less numerous, and they are permanent in Calamocrinus as well as in Thaumatocrinus, as suggested by P. H. Carpenter.

Schlüter and Meek speak of the upper series of the interradial plates as corresponding to the pinnules of free arms. It is difficult to understand this, as in Calamocrinus we have both the interradials and the large basal pinnules; although, as Carpenter has shown, there are many recent Crinoids (Pentacrinus, Metacrinus) in which the basal joints of the large lower pinnules are closely fitted together.

Carpenter (Chall. Rep., p. 45) considers the vertical series of plates of the anal side, resting upon a basal below and gradually diminishing in size in such genera as Onychocrinus,* Taxocrinus, Reteocrinus, and Xenocrinus, as similar to the anal appendage of Thaumatocrinus, only differing from it in forming a part of the body, "being bound in with the rays by minute interradial plates which are not present in Thaumatocrinus."

## VENTRAL SURFACE.

Seen from the actinal side, the five branches of the food groove of the ventral surface of the disk (Plate VI. Fig. 1) radiate from the angles of the orals. They are protected by the comparatively stout and prominent lateral and covering pieces of that part of the ventral disk which, when brought into contact, practically close the food groove. The food groove is simple to the first branch leading to one of the lower pinnules. The first right hand branch of the anterior food groove leads to the first

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* Meek and Worthen say the space between the arm-like plates and the vault is occupied by minute pieces, and that these are all in direct continuation with the vault.

pinnule, the second fork on the same side to the third pinnule, the third fork on the left to the second pinnule. In the right anterior food groove, the first fork leads to the fourth pinnule; the second branch, the posterior interradium, leads to the first pinnule, the third to the second, and the fourth to the third pinnule. In the right posterior, the first fork leads to the first pinnule, the second fork on the same side to the third pinnule, the third fork on the opposite side to the second pinnule, and the fourth fork to the fourth pinnule. In the left anterior groove, the first fork to the left leads to the second pinnule, the second fork on the opposite side to the first pinnule; the third fork on the same side as the first fork leads to the fourth pinnule. In the left posterior groove, the first fork leads to the first pinnule, the second fork to the third pinnule, the third fork to the second pinnule, the fourth fork to the fourth pinnule.* The first and second forks encroach upon the left posterior interradium, the third on the anal. The joints of these lower first pinnules form a solid arch over the food groove, bending as they do closely upon the surface of the ventral disk, and are in marked contrast to the other pinnules along the arms and its forks, in which only one or two joints cover the continuation of the perisomatic plating along the sides of the arms. Compare Plate IV. Fig. 1, and Plate V. Figs. 1, 2, 4, with Plate V. Figs. 5, 6, 7.

De Loriol † says, " Nous ignorons encore comment s'opérait l'occlusion de la cavité qui renfermait les parties molles de l'animal. Il paraît fort probable que cette cavité était recouverte non d'une voûte solide, comme dans la plupart des Crinoïds paléozoïques, mais d'une membrane fortifiée par de nombreuses petites pièces calcaires qui leur donnait de la fermeté."

A few years later, de Loriol confirms this,‡ for in 1887 he figures (Plate III. Figs. 1, 1a-e) the ventral disk of A. Roissyanus, so that we have for the first time an accurate idea of its structure. The conical sac figured by de Loriol is covered with plates irregular in outline, thin, contiguous,

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* Carpenter in a letter calls attention to a curious point of resemblance between Metacrinus and Calamocrinus in the characters of the disk. In both cases the ambulacra of the lower pinnules start directly from the primary trunk, and not from its two forks, as in most Crinoids. See Plates 39 and 43 of the Challenger Report.

† Note sur le Genre Apiocrinus. Association française pour l'Avancement des Sciences, Comptes Rendus de la 11me Session, p. 335 (p. 334). La Rochelle, 1882 (Paris, 1883).

‡ Note sur quelques Échinodermes fossiles des Environs de la Rochelle, par P. de Loriol, p. 313. Académie de la Rochelle. Société des Sciences Naturelles de la Charente Inférieure, Annales de 1886, Tom. XXIII., 1887.

resting upon the solid interradials. The interradial plates of this specimen differ as regards their shape and arrangement in each interradium. He could not find any trace of the furrows leading from the arms to the buccal orifice, nor could he satisfy himself it was placed at the extremity of this sac. He speaks, however, of a multitude of microscopic pieces to be seen piled opposite one of the rays, and I am inclined to consider the conical sac of de Loriol the anal proboscis, and to think that in a better preserved specimen we may be able to trace the ambulacral furrows, though they may be quite closed by just such movable covering plates as he has observed. The ventral sac is even more mobile than the anal sac of Calamocrinus, judging from the size of the plates covering it, and from what de Loriol says of their thickness. In fact, all the interradial plates he figures are comparatively smaller than those of Calamocrinus, and pass earlier into genuine irregular perisomic plates.

In the case of a specimen of Apiocrinus magnificus, de Loriol speaks of the interradial plates as thin and flexible, forming a sort of swelling (Plate III. Figs. 3, 3ª, 3ʰ). In a well preserved calyx of Millericrinus Fleuriansianus (Plate III. Fig. 2ª) the walls of the cavity are deeply grooved, the petaloid depressions for the reception of the chambered organ are large, and the canals which limit them well defined.

Wagner * discovered a specimen of Encrinus Wagneri with a well preserved vault extending to the upper articulation of the first radials. The large conical vault is composed of circular and elliptical larger and smaller granules and plates. The plates are well specialized, with a most distinct suture. The larger plates were in close and solid connection, which, as Wagner says, closely resembles the vault of Apiocrinus Roissyanus described by de Loriol, having a considerable rigidity and perhaps a slight degree of pliability.

Buckland † gives an excellent figure of the "plated integument of the abdominal cavity" of Pentacrinites briareus.

Von Koenen ‡ in the abstract of his larger memoir on Muschelkalk Encrinites, speaks in Dadocrinus of remains of plates to be seen between the spaces of adjoining arms of the second and third radials, which are to be considered as perisomic. Dadocrinus and Encrinus seem according to him

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* Ueber Encrinus Wagneri Ben. aus dem unteren Muschelkalk von Jena. Richard Wagner, Zeitsch. d. Deutschen Geol. Ges., 1887, XXXIX., p. 822.

† The Bridgewater Treatises. Treatise VI., Geology and Mineralogy, Vol. II. Plate 51, Fig. 2.

‡ Neues Jahrbuch f. Mineral., 1887, II., p. 86.

to have as great relationship with the more recent Crinoids like Millericrinus as with the certain palæozoic types like Poteriocrinus.

Meek gives in Volume 1. of the Report of the Geological Survey of Ohio, Plate 11. Figs. 3ª, 3ᶜ, a view of the vault of Glyptocrinus O'Nealli, showing it to consist of a large number of minute pieces, with large interradials.

In Saccocrinus* the plates of the calyx certainly pass from the base as gradually as is possible to the edge of the base of the arms, from large plates to smaller ones, and still smaller ones forming the vault; and the casts figured show most distinctly the course of the subtegminal ambulacra and the great development of the interradial system.

In Glyptocrinus,† Miller states that he has most distinctly traced the continuation of the vault up the inner sides of the arms for the distance of an inch above the vault. The pinnules do not cover the ambulacral grooves. The vault plates become smaller as they approach the inner face of the arms, and, continuing to diminish in size, form a somewhat granular contiguous element that covers the ambulacral furrows. The anal plates are large, forming an irregular pyramidal structure.

The latest views of Wachsmuth and Springer on the nature of the vault of Crinoids may be summed up from their own statements. We do not materially gain in our comparisons by taking into account the manifold types of structure in the calyx of palæozoic Crinoids which culminate in the subcarboniferous period; and we really need to take into service only those of the principal types which have the greatest palæontological range, and help us distinctly in our understanding of the more recent Crinoids.

In the Articulata of Wachsmuth and Springer, where the vault has been observed, it is found to consist of many small irregularly arranged plates, is more or less flexible, the ambulacra are subtegminal, and in the Ichthyocrinidæ possess a small anal proboscis.

In the Camerata the vault, on the contrary, is composed of large massive plates; and in many types a regular arrangement has been traced in the dome plates, which, however, it is often very difficult to trace in groups in which the anal proboscis takes a great development, or where the vault is composed of more numerous plates; and the relationship of this vault

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* S. A. Miller, Journ. Cincinnati Soc. of Nat. Hist., 1881, Vol. IV. Plate IV.

† Glyptocrinus re-defined and restricted, by S. A. Miller, Journ. Cincinnati Soc. of Nat. Hist., 1883, Vol. VI. p. 217, Plate XI.

to that of the recent Crinoids can only be traced by a careful comparison with the oral plates of some of the Idunata and with the young stages of Comatula.

In the latter we have a subtegminal mouth and interradial orals, and we have in the former interradial orals and both subtegminal and exposed ambulacral furrows, where the ambulacral covering plates and side plates do not reach the interradials, whether they be orals or other interradial plates have encroached upon this space and covered the central part of the disk, exactly as we find in Spatangoids with disconnected apical systems, the intervening space filled by the junction of opposite interambulacra to occupy the space of plates belonging to the ambulacral and apical systems; but here they are pushed aside, while with some Crinoids they are covered.

There is no line of demarcation between actinal and abactinal in the perisomic plates, and none in the Cystideans; and there are all possible stages between Crinoids in which the contrast is sharply defined, and those in which it is indistinct and impossible to draw the line. And this encroachment of the interradials can nowhere be better observed than in such a vault structure as Cyathocrinus malvaceus, in which they are few in number and simulate the arrangement of the oral plates.

The above shows the great changes which have taken place in Wachsmuth's earlier views of the homologies of the vault of the palæozoic Crinoids and of the disk of Neocrinoids, which at one time he considered it impossible could in any way be homologized.

Carpenter in the Challenger Report (p. 185), after an extended discussion of the structure of the vault in palæozoic and other Crinoids, sums up his conclusions regarding the homologies of the vault of the palæozoic and Neocrinoids as follows: " In Cyathocrinus, Platycrinus, Glyptocrinus, Reteocrinus, and Xenocrinus, as well as in the Ichthyocrinidæ, the resemblance to the Pentacrinidæ, Apiocrinidæ, and Comatulidæ is such as to leave no reasonable doubt that the so called vault of the Palæocrinoids is homologous with the ventral surface of the body in the Neocrinoids. . . . Yet the mouth may have been subtegminal."

## ORALS.

The orals and adjacent side plates forming the sides of the angles of the mouth in Calamocrinus are interesting from their structure, differing,

as they do, from the oral plates of all other known Neocrinoids.* The oral plates of modern Stalked Crinoids are usually flat, thin triangular plates, occupying the interradial angle between two adjoining food grooves. These oral plates are generally perforated with a few water pores, similar to the pores we find on the rows of perforated perisomatic plates which separate the side plates of the food groove from the stouter imperforated interradial plates above the radials.

The shape of the oral plate seen from above is convex, with an anterior keel. The general appearance of the oral plates and adjoining side plates on one side of the angle of the mouth is shown in Figure 7 of Plate IX. The lower part of the side plates is not cleared of the connective tissue uniting them. Seen facing the angle of the mouth, the oral plate is high, irregularly rectangular, with rounded corners, resembling somewhat a short femur (Plate IX. Fig. 10. *o*). A prominent rounded keel of dumb-bell shape, *o'*. extends for about half its length on the anterior face. Seen in profile from the left (Plate IX. Fig. 11), the position of the keel, *o'*, is shown as it passes rather abruptly into the upper face of the oral and very gradually into the lower part of the oral. A second keel, arrow-head in shape, projects laterally from the face of the oral. The outline of the oral plate opposite the central keel is concave. Seen from the other face, the distal extremity of the oral is more pointed (Plate IX. Fig. 9), and the lateral keel of that face runs in an undulating curve to the lower end of the oral. The orals, as well as the adjoining side plate, are closely and compactly reticulated (Plate IX. Figs. 8–14). The oral plate. *o*. and its nearest side plates, *a, b, c*. as they appear when cleaned. are shown in Figure 8 of Plate IX. Figures 9 to 14 of the same plate are the oral and the side plates. corresponding to *o, a, b, c*, of another mouth angle. The first side plate sometimes carries a keel like the lateral keel of the oral (Fig. 12). These side plates also seem to vary considerably in outline. Compare Figures 12

* The persistent oral plates of Holopus, Hyocrinus, Rhizocrinus, and Thaumatocrinus present in each a different stage of development (Chall Rep , p. 72). The orals are small in Rhizocrinus, and in Calamocrinus comparatively still smaller. They are separated more widely from the edge of the disk by a large and thick perisome covered by a wide belt of interradial plates. They differ from the orals of Hyocrinus and Rhizocrinus in being imperforate: at any rate. it is impossible to detect the water pores in the midst of the limestone reticulation of the so called orals  Carpenter, in a letter, suggests that they may be the fused proximal plates of two ambulacra, as they do not seem to be sufficiently differentiated from the big plates of the ambulacral skeleton. In all the Pentacrinidæ and Comatulæ as shown by Carpenter, except Thaumatocrinus, the orals eventually undergo a process of resorption ; this " commences in Comatula before the young detaches itself from the larval stem. and no traces of the orals are to be found in the adult."

to 14 of Plate IX. with Figure 8, *a*, *b*, *c*, which represent corresponding side plates. The oral plate varies also in Figures 8 and 9. The upper end of the oral is somewhat askew, and hence the profile (Fig. 11) seems more different than it really is from that of the corresponding profile (Fig. 9). Figure 7 is drawn somewhat obliquely to show the difference in the two sides of the oral plate, *o*, on the upper extremity above the central keel, *o'*.

## STEM.

The stems of the three specimens show very considerable differences, and the different parts of the same also vary greatly in their physiognomy. In the upper part of the stem the rings vary very materially, from being quite smooth (Plate XVIII. Fig. 1) to being strengthened by a strong central ridge (Plate XVII. Fig. 1). In the latter case we have serrated sutures, while in the former stage they are smooth. In another specimen the upper joints combine the characteristics of the other two. They are smooth, with smooth sutures, passing from rings with smooth sutures and small imperceptible tubercules (Plate XVII. Fig. 10) along the median line to rings with connected tubercular ridges with smooth sutures on the ridges, and lower down along the stem to rings with serrated sutures and marked central ridges (Plate XVII. Figs. 8, 11).

In the specimen shown in Figure 2 of Plate XVIII., the smooth rings pass directly into rings with slight ridges and somewhat irregularly and indefinitely serrated sutures, and these pass gradually into rings with more finely serrated sutures and with less and less distinct median transverse ridges (Figs. 4^b. 5^c). until they pass again into regularly discoidal rings with smooth sutures (Fig. 6^d); and it is rings of this character, but more flattened (Fig. 9), such as are figured from another fragment of a stem, which continue to the very base of the stem, at the same time slightly expanding in width towards the base, much as they have been figured for the fossil species of Apiocrinus and Millericrinus. The upper rings of the stem adjoining the calyx expand slightly, and pass as it were into the outline of the calyx (Plate XVII. Figs. 1, 8, 9, 10. Plate XVIII. Fig. 1). But this expansion of the basal rings of the stem does not compare with the extreme condition which is reached in the fossil Apiocrinus, in which the upper joints form a part of the cup outline of the calyx.

In those parts of the stem intervening between the lower portion nearer

the base, in which the rings have become absolutely discoidal, and that in which the rings are ribbed, we find a transition in some cases in which the ribs become very indistinct, and are merely marked by an angular outer outline (Plate XVII. Figs. 12, 13, 14), before they become rings with the convex outer outline of the lower part of the stem. The specimen in which the ribs are most distinctly marked, Plate XVII. Fig. 2, presents at first sight a striking contrast to the stems of the other specimens, and, with the stem of Figure 8, is a good example of the great variation we may find in the joints of stems of one and the same species. Neither the lower part of the stem of Figure 2, nor that of Figure 8 is known. The only portions of stems which appear to form parts of a single stem are the fragments figured in Plate XVIII. Figs. 2, 7, 8, 9, which probably belong to the same calyx, and were part of a stem from twenty to twenty-two inches in length, Figure 2 fitting into the calyx of Figure 1. The parts in Figures 7 and 8 form a piece of the stem intermediate between it and that figured in Figure 9, nearer the base.*

In the upper part of the stems of all the specimens flat rings are intercalated between the rings with ribs, and form, as it were, a base upon which the wider-ribbed rings rest. See Plate XVII. Figs. 4, 5, 11; Plate XVIII. Figs. 3ᵃ, 4ᵇ. These flat rings become wider in proportion as they are distant from the calyx; compare Plate XVII. Figs. 4 to 7, of one stem in which they gradually pass into rings all of which are ribbed, as they are in Plate XVII. Fig. 2, at the lower end of the part of the stem figured. In the stem figured on Plate XVII. Figs. 8, 10, the flat rings are continued farther from the calyx, while in the stem figured on Plate XVIII. Fig. 2, they extend but a short distance from the calyx, and soon pass into rings (Plate XVIII. Fig. 5ᶜ) but slightly ribbed, coming below a part of the stem in which there is only an occasional ring found with a slight rib, or projecting beyond the general outline of the stem (Plate XVIII. Fig. 4ᵇ). It is probable that Figures 12 and 13 of Plate XVII. formed a part

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* If we may judge of the length of the stem of Calamocrinus from that of some fossil species of Apiocrinidæ of which the stem has been found complete, the length given above is probably a moderate estimate. The stem of Guettardicrinus dilatatus was about thirty-five inches in length ; that of Apiocrinus Roissyanus, thirty-six inches; of Apiocrinus elegans, about twenty-eight inches. In Apiocrinus Murchisonianus the stem was somewhat stouter, and not more than twenty-four inches long ; in Millericrinus simplex the stem is thirty-six inches ; in Millericrinus polydactylus the known stems vary from twenty to thirty inches, and in M. gracilis the stem was about thirty-two inches. In Millericrinus Pratti, of which Carpenter thinks the extremity of the stem was not fixed, the length of the stem was probably more than 50 millimeters.

of the stem belonging to Figure 8, in which the very prominent transverse
ridges had passed into merely angular sides of the column.

Comparing the outline of these stems with similar parts in fossil species
of Apiocrinus, Guettardicrinus, and Millericrinus, we find that the serrations
of the suture of the basal part of the stem of Calamocrinus are closer than
those of Apiocrinus or their fossil allies, the suture being generally a double
line showing the closest kind of reticulated structure. See the drawings of
the upper part of the joints. Plate XVII. Figs. 1, 9, 10. The median part
of the stem resembles somewhat the stem of those species of Millericrinus
in which the sutures were nearly smooth, without the tendency to form an
angular stem, while the upper parts of the stem, with its prominent ridges
and flat rings intervening (Plate XVII. Fig. 5) between them, remind us
very strongly of a similar structure in the stems of several species of
Millericrinus.

The stem both of Guettardicrinus and of Apiocrinus is smooth, the ar-
ticular face of the former being, like that of the basal part of the stem of
Calamocrinus, flat, with a large number of ribs, here and there bifurcated.
But the median parts of the stem, as well as the upper parts close to the
calyx, resemble more the structure of the stem of Millericrinus in the man-
ner in which the upper stem joint is connected with the calyx, as well
as in the ornamentation of parts of the stem in the ribbed and flat joints,
which however in Calamocrinus shows no trace of being pentagonal, as is
the case in many species of Millericrinus. Nor is the ornamentation of the
stem as varied as it is in that genus, being limited to the few granules
in certain of the rings of the upper part of the stem, to the differences
in the character of the transverse rib of the joints in different parts of
the stem, and to the serration of the sutures due to the size of the ribs
uniting the articular faces of the stem joints.

There were probably eight joints of the upper part of the stem (Plate
XVIII. Fig. 2) crushed, and its condition indicates that these joints un-
doubtedly formed the part of the stem immediately in contact with Plate
XVIII. Fig. 1. The upper stem joints of this specimen were smooth, with
slightly undulating articulations, forming a somewhat indented outline, the
eight upper joints measuring 7.55 mm. in height. The diameter of the
upper stem joint is 6.1 mm., while the diameter of the stem at the sev-
enth joint is only 5.50 mm., showing a greater tendency toward a widening
in the upper part of the stem than in Plate XVII. Fig. 1, but a far less

marked trumpet shape than the extreme upper end of the stem (Plate XVII. Fig. 8) of the specimen, in which the upper part of the calyx has been torn off.

In the piece of the stem of Plate XVII. Fig. 8, the upper eleven joints measure 8 mm. in height. The uppermost joint is smooth, and every other joint has a median ridge. There are from sixteen to eighteen undulating serrations to each joint. The diameter of the upper joint is 5.9 mm., while at a distance of 8 mm. below, the diameter of the stem is still 5 mm.

This piece of stem is 92.50 mm. in length. Its diameter at the lower end is 3.75 mm.; at the base of the calyx, 6.1 mm.; at a distance of 14 mm. from the upper joint, the diameter is 4.5 mm. To 14 mm. there are nineteen joints from the upper joint. The first six joints occupy 4.25 mm. At the smaller extremity twenty-two joints occupy 11 mm. In the middle part of the stem twenty-two joints also occupy 11 mm. The five upper joints are the largest.

The first six rings are smooth, with here and there slight granulations on joints below the calyx. The second, fourth, and sixth rings are slightly granulated, or nearly smooth. The outer edge of the column is also smooth. Below the seventh, every other ring is granulated, and passes gradually into a rib, the alternating ring having a slight rib in the middle. At a distance of about 20 mm. from the base of the calyx, the rings alternately carry a rib to the extremity of this fragment of stem. The articulations are but slightly serrated, as in the second portion of the stem. The alternating joints are smooth.

A piece of stem 89 mm. long (Plate XVIII. Fig. 9), curved towards the upper end; 5.85 mm. in diameter at the small end, and 7.30 mm. in diameter at the large end; seven joints to 10 mm. at the big end, eight joints to 10 mm. in the middle, and nine joints to 10.5 mm. at the small end. This piece must have been broken very close to the base of attachment of this specimen, judging by the piece of stem collected in 1891 off Morro Puercos.

The long piece of the basal part of the stem of a specimen collected by the "Albatross," in 1891, off Mariato Point, in 782 fathoms, fortunately retained the last joints, showing the mode of attachment of the stem in this genus. The root is formed by the spreading of the last joint encroaching upon a part of the last joints of the stem, thus forming a base of about three times the diameter of the stem (Plate XXVIII. Figs. 2–4).

Figures 2 and 3, Plate XXVIII., give an asymmetrical view of the three incomplete joints which go to form the spreading base, as seen from the curved side of the stem. Figure 4 shows the same joints seen from the convex side of the curved stem. The line of separation between the expanded base and the joints is very distinct. The expanded stem joints forming the base of the stem of Calamocrinus bear a striking resemblance to the root of Anomalocrinus incurvus figured by Meek (Geol. Survey of Ohio, Palæontology, Vol. I. Plate 2, Fig. 6ᵈ).

The diameter of the piece of the stem collected in 1891 is 10 mm. at the third ring above the basal expansion (Plate XXVIII. Fig. 2). From that point there are six rings to a length of 10 mm.; about one third of the length from the base there are ten rings to a length of 10 mm.; and near the extremity of the piece figured, where the diameter is reduced to 4 mm., there are twelve rings in a length of 10 mm.

Figure 5, Plate XXVIII., shows the upper part of the stem with the wedges of the new arm joints intercalated between the older joints. From the size of these new joints near the summit, this specimen must have been an old one, as it shows no trace of the young joints indicated by narrow wedges in the other specimens figured. This older specimen shows also the peculiar disconnected intercalated stem joints figured in many fossil species.

The longest piece of stem was 180 mm., with a diameter at the large end of 5.30 mm., and at the small end of 4 mm. About 110 mm. of this is straight, the rest slightly curved towards the large end, much as in Figure 8, Plate XVII. At the smaller extremity sixteen joints measured 20 mm. in height; near the middle of this fragment of stem ten joints measured 10 mm. in height, and at the larger extremity sixteen joints measured only 10 mm. in height. The serrations of the articulations are quite distinct near the wide end. The ridges of alternating joints gradually disappear, towards the first quarter of the stem only every fourth or fifth joint has a slight ridge, and towards the lower third of this part of the stem these ridges disappear entirely and the joints become smooth, the serrations disappearing at the same time.

A fragment of a stem, shown in Plate XVIII. Fig. 2, is 70 mm. long, with the upper end crushed. Twenty joints to 11 mm. at the top; in the middle, twenty-four joints to 10 mm.; below this, eighteen joints to 13 mm.; and at the bottom, thirteen joints to 13 mm. The diameter of the upper

end is 4.9 mm., and of the small end 4 mm. At the upper part of the stem the joints are alternately smooth and ridged (Fig. 3), until at the lower third of the stem the smooth joints show indications of a slight ridge (Fig. 4), and gradually all the joints become ridged (Fig. 5).

Another piece (Plate XVIII. Figs. 7, 8) is very slightly curved towards the stouter end, 135 mm. long, 5 mm. in diameter at the large end, and 4 mm. at the smaller end. There are seventeen joints to 20 mm. both at the smaller and at the larger end; the articulations of both Figures 7 and 8 are very smooth and very distinct.

A piece 150 mm. in length (Plate XVII. Figs. 12, 13) is slightly curved in the middle, 4 mm. in diameter at the smaller end, and 4.1 mm. at the larger end. There are seventeen joints to 20 mm. at the larger end, and eighteen joints to 20 mm. at the smaller end. The articulations are like those of Figure 14.

A piece of stem, 130 mm. long, practically straight, has at the smaller end nineteen joints to 20 mm., and seventeen joints to 20 mm. at the upper end. The diameter is 4.4 mm. at the smaller end, and 5.25 mm. at the larger end. It resembles Plate XVIII. Figs. 7, 8.

One piece, 115 mm. long, is slightly curved. The diameter is 3.7 mm. at the small end, and 4 mm. at the other. It has fourteen joints to 20 mm. at the small end, and fifteen joints to 20 mm. at the large end. The joints are smooth and sharply ridged, giving a zigzag outline to the edge of the column, somewhat as in Plate XVII. Fig. 12.

## The Top Stem Joint.

The top stem joint (Plate XXI. Fig. 1) is slightly arched from the outer edge towards the central portion of the joint, which is somewhat sunken to receive the quinquelobular new young joint (Plate XXI. Figure 3), which occupies a part of the space intervening between the upper surface of the top stem joint and the lower face of the basal ring (Plate XIX. Fig. 1).

The upper face of the top stem joint is finely striated from the outer edge inward, and shows a series of irregular radiating slightly raised angular ridges, similar to those figured by D'Orbigny and de Loriol on the upper face of the *article basal* of the Apiocrinidæ. Towards the median part of the surface of the joint the reticulation becomes cellular, losing its radiating arrangement, and gradually passes from a comparatively close and

compact reticular system to the delicate open system of meshwork imme-
diately surrounding the opening of the axial canal (Plate XXI. Fig. 4).
The lower face of the upper joint (Plate XXI. Fig. 2) is flat, and the
raised angular ridges are less marked, but otherwise it does not differ
materially in its structure from that of the upper face. The quinque-
lobular disk (Plate XXI. Fig. 3) has the same reticulation with the inner
part of the stem joints. It has a delicate open meshwork surrounding the
axial canal, which passes gradually into a closer and more compact lime-
stone plating towards the periphery and in the wedges forming the angles
between the adjoining indistinct lobes. This disk seems to differ in its
mode of origin from that of new joints, and I am inclined to look upon
this disk as the representative of the anchylosed infrabasals detected in
the Apiocrinidæ.* The new joints, if we can judge from the figures I
have given, appear at first towards the outer edges of the older rings as
delicate limestone spurs extending towards the centre, while in the case

* With the exception of Encrinus and Apiocrinus, the infrabasals have not been described in the
more recent types of Crinoids, but they are known in about half of the palæozoic Crinoids.

The infrabasals of Encrinus, as figured by Beyrich (Crinoiden d. Muschelkalks, p. 1, Plate I.
Fig. 1c), are entirely enclosed and hidden by the upper stem joint, and occupy exactly the same posi-
tion as the lobed plate I have described at the summit of the uppermost joint of Calamocrinus.
De Loriol (Monog. des Crinoides de la Suisse, p. 7, 1878-79) considers the supplementary basals
of Encrinus as forming no part of the calyx, but as belonging to the uppermost stem joint, which
he has called the "article basal." De Loriol figures in the Paléontol. française (Tom. XI.
1e Partie, Crinoides, 1882-84) five small plates radially placed upon the centre of the summit of the
top stem joint of two species of Millericrinus, M. polydactylus (Plate 110, Figs. 1a, 2a, p. 553) and
M. D'Orbignyi (Plate 116, Figs. 1b, 1c, p. 566). They do not appear at all upon the exterior of the
calyx, but rest upon the central part of the enlarged uppermost stem joint, and are concealed by
the basals outside of them.

Judging from the little we know of the young stages of the dicyclic palæozoic forms as described
by Wachsmuth and Springer (Transition Forms in Crinoids, Proc. Phil. Acad., 1878, p. 229), the
infrabasals are very highly developed, and gradually become less prominent as the young grow older.

This seems to show that the infrabasals may have become rudimentary, or have been lost alto-
gether in those forms in which it has not been observed. The discovery of infrabasals by Bury in
the embryo of Comatula (Morphol. Studies, p. 148), and their subsequent resorption, goes far towards
making this a plausible explanation of the existence of infrabasals in the older types and their absence
in the more recent ones: although, as Neumayer justly remarks, we should be very cautious in taking
the development of Comatula, a geologically recent and quite aberrant type, as characteristic of that
of the Crinoids as a whole.

The infrabasals of Encrinus, which support the basals, are in Stemmatocrinus represented by a
flat plate. Carpenter is inclined to look upon this as the top stem joint, the article basal of Apiocrinus
and Millericrinus. This flat plate may have arisen from the anchylosis of the infrabasals, or it may
in some cases correspond to the upper stem joint. This is the case in Rhipidocrinus, where the infra-
basals are apparently anchylosed into a central plate.

The formation of the centrodorsal in Comatula and in M. Pratti, in which the infrabasals are
anchylosed with one or more stem joints, may occur in other cases.

But as we know the development of Crinoids only from a single type, the representative of a group
with a modified calyx, we should be careful, as Carpenter has already suggested, in making compari-
sons based upon embryological data with the endless and complicated types of the palæozoic genera

of the disk found on the upper face of the top stem joint its outer edge does not reach as yet to the point where new stem joints arise, and is not attached to the limestone meshwork of the top stem joint, as is the case with the young stem joints which originate between two older ones. See Plate XXIII. Fig. 3, and Plate XXIV. Fig. 7.

The structure of the joints following the top stem joint is markedly different from it. The distal face (Plate XXI. Fig. 6) of the sixth joint below the top stem joint shows stout short radiating lines only on the outer edge, such as we find in the periphery of all the stem joints, forming a more or less marked milled edge. On the outer quarter of the surface there are a number of stout radiating ridges, from four to five, between a second inner set of fourteen radiating ridges, more or less comma-shaped, which extend to the outer line of the open meshwork surrounding the axial column (Plate XXI. Fig. 6). The proximal face of the same joint (Fig. 7) corresponds in its structure to the distal face; the primary radiating ridges, however, are replaced by a corresponding number of sockets.

In the distal and proximal faces of the ninth joint (Plate XXI. Figs. 8, 9), the arrangement of the reticulation in radiating lines on the outer part of the faces of the joint, between the sockets and corresponding ridges, is well indicated. In these joints there are sixteen primary ridges (Fig. 8) bifurcating near the edge, and the opposite face shows the corresponding sockets which fit to the distal face of the eighth joint. This proximal face shows the sunken lobes upon which may rest a new stem joint similar to the young joint (Fig. 5), with sixteen lobes formed between the eighth and ninth joints.

In the upper part of the stem in which we find ribbed joints like those of Plate XXII. Figs. 1 and 2, the primary radiating ridges are from sixteen to eighteen in number. They are flattened, leaving large triangular depressions between them (Figs. 3, 4); the broad areas being sunken in the proximal faces (Fig. 3), and raised in the distal faces (Fig. 4). Young stem joints lying between the ribbed joints and the flattened joints, such as those of Figure 2, in which the outer lobes find their way to the surface of the column, are shown in Figure 5, which represents a segment of one of these young joints adjoining the distal face (Fig. 4). A segment of a similar, but younger, intercalated joint, which has not yet lost its lobular outline, is represented in Figure 6. The passage of the reticulation on the faces of the joints, from the compact ridges of Figure 4 to a

reticulation becoming gradually more open as we pass towards the centre to the axial canal, is shown in Figures 7 to 9.

In that part of the stem where there are no flat rings, but only ribbed ones, the radiating ridges and corresponding depressions on the distal and proximal faces correspond to the serrations of the sutures in Plate XXV. Figures 3 and 4. In a ring with a large number of sutural serrations, in Figure 5, the secondary serrations are still more marked, and represented by shorter radiating ridges extending but a little way inward from the periphery (Fig. 6). The radiating ridges of older joints (Fig. 9) become serrated or undulating disconnected lamellæ (Fig. 10).

In those parts of the stem in which the axial canal occupies a proportionally large space of the face of the joint (Plate XXV. Figs. 7, 8), the radiating lamellæ of course do not extend even to the edge of the axial chamber in the joint (Figs. 3, 4, 6), but are lost in the more open reticulation of the face of the joint near the outer edge of the axial cord.

As the axial ring becomes proportionally smaller, the radiating ridges extend nearer the centre of the face of the joint (Plate XXVI. Figs. 5, 6), and at the same time begin to show traces of the peculiar arrangement of disconnected radiating ridges (Fig. 4), which becomes more prominent in some of the lower stem joints. In an older joint (Fig. 2) the central reticulation also assumes a radial arrangement, and at the same time disconnected short arcs form part of the general circular lines crossing the radiating lines of the middle third of the face of the joint (Figs. 2, 3). When we come to the lowest joints of the stem, the circular lines of Figure 2 have disappeared, and the radiating lamellæ extend to the very edge of the axial cord (Fig. 9). The lamellæ of the outer edge of the face which extend to the periphery from the edges of the radiating lamellæ (Fig. 10) form a narrow bevelled plane of flat ridges and grooves, which leave an open space between the upper and the lower edge of the sutures (Figs. 1, 11). The reticulation of a part of one of the joints (Fig. 8) resembles in general that of the Hexactinellidæ, each node sending off six spokes to form the connecting network.

The lower face of the basal ring (Plate XIX. Fig. 1) is bevelled, rising from the outer milled edge towards the axial canal, so as to leave quite a cavity between this face of the basals and the upper face of the top stem joint. The lower face of the anchylosed basal ring is marked by indistinct radiating ridges extending from the milled edge of the ring to

the axial cord opening. These ridges are similar to those of the faces of the top stem joint, but less prominent, and similar to those of the corresponding parts in the Apiocrinidæ, figured by D'Orbigny and de Loriol.

We do not find in the top stem joint of Calamocrinus the distinct elevations and depressions for the reception of the basals characteristic of the Apiocrinidæ.

It is interesting to note so marked a difference in the structure of the faces of the stem joints in Calamocrinus, Apiocrinus, Millericrinus, and the like, when contrasted with the bifascial faces of the lower part of the stem joints of Rhizocrinus and Bathycrinus. No such bifascial faces are found in the former genera, while the faces of the upper stem joints of Rhizocrinus, of Hyocrinus, and of Bathycrinus show no such structure as characterizes the lower stem joints.

It is interesting also to observe here, what does not seem to have been noticed by previous writers who have examined Rhizocrinus, that the upper stem joint is convex at its upper face, and that in the concave space of the basal ring is found a delicate, exceedingly thin five-lobed young joint, entirely hidden within the basal ring. This young joint is apparently identical with the similar joint described in Calamocrinus. The top stem joint was three times as wide as high, and followed in the specimen examined by two similar joints; the fourth joint was nearly as high as wide, while the fifth joint was higher than wide. Neither of these five joints possessed bifascial faces. They were slightly convex on the outer edges of the upper face, with a depression towards the axial canal.

The stem joints of Hyocrinus, which bear the closest resemblance to those of the Apiocrinidæ, have been described by Sir Wyville Thomson,[*] and also by Carpenter.[†] They vary considerably, some being "perfectly plain," others "being marked with a pattern of radiating grooves and ridges."

We know nothing as yet of the root of Hyocrinus, but in the case of Rhizocrinus, at least, the structure of the root, branching into numerous rootlets, plainly indicated that it was adapted to thrive in a muddy or soft bottom; and such was generally the character of the ground upon which the "Blake" dredgings showed it to be most abundant. In the case of the Apiocrinidæ proper, however, they (Guettardicrinus, Millericrinus,[‡] Apio-

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[*] Journ. Linn. Soc., 1878, Vol. XII. p. 53.    [†] Chall. Rep., p. 32, Plate V. c, Figs. 4, 5.

[‡] P. H. Carpenter considers Millericrinus Pratti and other Apiocrinidæ as not having lived attached, but with a free extremity, as in Woodocrinus. See his paper on Millericrinus Pratti. Q. J. Geol. Soc. London, 1882.

crinus), as well as Calamocrinus and Bathycrinus, must have lived upon rocky bottom, upon which their solid expanding conical base became firmly attached. In the case of the Pentacrinidæ which I dredged in the West Indies, they were most abundant at St. Vincent and Barbados, on rocky ledges where nothing but the "swabs" of the bar and tangle were of much use in bringing up specimens.

## STEMS OF SOME FOSSIL CRINOIDS.

Thus far little attention has been paid to the mode of origin of new stem joints. According to Thomson, new stem joints are added immediately below the centrodorsal plate in the Pentacrinoid of Comatulæ. Carpenter has figured the mode of development of the young joints in Pentacrinus Wyville-Thomsoni (Chall. Rep., Plate XXII.) both as young joints appearing on the top of the upper stem joint for the time being, and as intercalated joints either of nodals or internodals. Quenstedt has done the same for Extracrinus (Plate 101, Fig. 24ª). I shall pass rapidly in review the figures which have been published of the principal types of stems among the fossil Crinoids, to facilitate hereafter the comparison of the mode of growth of the stem of palæozoic with that of the recent Crinoids.

The origin of new stem joints apparently varies greatly in the different groups, and modifies to a considerable extent the appearance of the upper part of the stem.

Every writer on the Ichthyocrinidæ has noticed the difference in the aspect of the upper part of the stem, which tapers considerably downwards, and is composed of short and even joints, which are followed abruptly by alternate high and short pieces, new joints being apparently formed some- · what below the twelfth plate.

The stem of Millericrinus Pratti varies very considerably, as has been shown by Carpenter,* who has described a series of stems varying from the pedunculate to the free mode of existence (Plate I. Figs. 5–8, 10, 12, 14), the majority of the stems tapering rapidly from above downwards, the last joints seeming to have fused. The mode of intercalation of what he considers as new joints in process of formation (Plate I. Figs. 1, 7, 10) is different from the process by which new joints force their way to the surface between the older joints in Calamocrinus.

* P. H. Carpenter. On some new or little known Jurassic Crinoids, Q. Journ. Geol. Soc., 1882, Vol. XXXVIII. p 32.

Judging from the analogy of the condition of the top stem joint in Cala-
mocrinus, and the formation of a new joint between it and the basals,
Carpenter is evidently correct in attributing the variation in the thickness
of the top stem joints in the specimens of Millericrinus Pratti which he
examined to a secondary deposition of limestone outside the upper stem
joints. I have been unable in Calamocrinus to trace any sign of pits
between the basals and radials, the so called "ovarian openings" of
Carpenter.

Billings also figures the stems of a number of palæozoic Crinoids, show-
ing, as in Heterocrinus (Geol. Survey, Decade 4, Plate IV. Fig. 5ª) and in
Dendrocrinus (Plate III. Fig. 7ª), the young joints crowded at the upper
part of the stem. Intercalated joints are shown in some of his figures,
as Rhodocrinus (Plate VI.) and Glyptocrinus (Plate VII. Figs. 2ᵇ, 2ᵈ, Plate
VIII. Fig. 1ʰ).

In one specimen of Heterocrinus kindly lent me by Messrs. Wachs-
muth and Springer, the outer edge of the wedge-shaped new joints are
plainly seen forcing their way out between the basals and the top stem
joint, and between the sutures of the succeeding joints. In another, the
wedges of the new joints, which are thin and disconnected on the lines
of sutures near the upper part of the stem, gradually become wider, and
form a very thin joint alternating with a stouter one; and still lower down
on the stem these new intercalated joints become thicker, but they still
show a marked difference in their diameter and height when compared
with the older stem joints.

In a specimen of Ectenocrinus with a tripartite base, the young joints
at the summit of the column appear to alternate irregularly from side to
side. These irregular wedges do not anchylose and form a single joint
extending across the stem, so that the inequality of growth of the two
sides of the stem or of the wedges themselves may account for the dis-
jointed wedges which are not unfrequently found in the stems of many
fossil Crinoids.

In a specimen of Glyptocrinus belonging to the Wachsmuth and Springer
collection, we find a small lobed ring with radiating ridges inside of the
basal ring.

In specimens of Cyathocrinus, the top joint is seen from the under side
within the infrabasals. This youngest joint is a small lobed disk resting
upon ridges and grooves, and not extending as yet, in the specimens exam-

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ined, to the outer edge of the old joint below it. This young lobed upper joint recalls the uppermost quinquelobular joint of Calamocrinus. But in Cyathocrinus this disk is ten-lobed, and distinctly grooved and ribbed radially, while it is not so in the young joint of Calamocrinus.

In Glyptocrinus plumosus, Hall[*] figures the top stem joint of the column as dome-shaped.

In Pacht's[†] observations on Dimerocrinites (Taxocrinus) oligoptilus, I find on Plate 1. Fig. 2', an excellent figure showing a transverse section of the basal ring with its mode of junction to the top stem joint. This joint is dome-shaped, considerably higher than the other stem joints immediately following it, but of the same diameter. On the top of this hemispherical joint is the pentagonal outline of the axial canal. There are no infrabasals, the radials themselves come nearly in contact with the stem, and are well separated by the basals, upon which rest five large interradials, followed by smaller interradials which unite the edges of the arms to the distichal axillary, thus forming a deep calyx, the parts of which differ in no wise from that of Calamocrinus except in unimportant structural features.

The figures given by Meek of some species of Platycrinus (Geol. Survey of Ohio, Vol. II. Plate XI.) indicate that new stem joints are intercalated between the older ones in the upper part of the stem, as also in Actinocrinus. In Forbesiocrinus (Ibid., Plate XII.) and Zeacrinus the very upper part of the stem is made up of narrow new joints, while in Poteriocrinus the new joints appear on a larger part of the stem.

Von Koenen[‡] has given figures of the upper part of a stem of Encrinus liliiformis, showing the grouping of the new joints extending across the stem intercalated between the older ones, as well as the younger joints, which as yet reach the edge of the stem only in one or two places (Plate. Fig. 10. a, b, c, d). In Calamocrinus these new joints extend to a, Plate XVII. Fig. 8, and to c, on Plate XVIII. Fig. 2.

The figures given by Beyrich[§] (Plate I. Fig. 12, and especially Plate II.) show that in the very upper part of the stem only are new joints formed,

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[*] Palæontology of New York, Vol. II. Plate 11, Fig. 2[b].

[†] Pacht, R., Verhandl. d. Kaiserl. Russ. Mineralog. Gesell. zu St. Petersburg, 1852-53 (1852).

[‡] A. von Koenen, Beitrag zur Kenntniss der Crinoiden des Muschelkalks, Abhandl. d. Konig. Gesell. d. Wiss. zu Gottingen, 1887, XXXIV., p. 13.

[§] Ueber die Crinoiden des Muschelkalks, Abhandl. d. Königl. Akad. d. Wissen zu Berlin, 1857, No. 1.

and that they soon assume their ultimate shape, gradually passing into the lower joints where the joints are identical, or nearly so, while in the upper part, where new joints are formed, they are not. Beyrich and von Koenen seem to have succeeded in tracing a regular order of appearance of the new joints. I could only say that from three to four new joints are intercalated between any two original sutures of that part of the stem where they are added by the gradual increase in height. I cannot understand why Beyrich asserts (*loc. cit.*, p. 7) that in the youngest stages the stem could be divided into two parts, in one of which the lower joints never possessed the flat shape of the young joints of the upper extremity, and *vice versa*. This certainly is not the case in Calamocrinus, and there seems to be no valid reason for the interpretation given by Beyrich to the difference in structure he observed in the upper and lower parts of the stem of Encrinus.

Hall figures[*] the upper part of the stem of Dendrocrinus longidactylus, showing plainly the new joints forcing their way to the surface between the older ones.

In Ichthyocrinus young joints appear to be most numerous also in the part of the stem immediately below the calyx.

In Poteriocrinus, Cyathocrinus, Platycrinus, Actinocrinus, and other palæozoic Crinoids, the same is the case, so far as can be judged from the numerous figures of parts of the stem which have been published in the Palæontologies of New York, of Illinois, of Iowa, and of Ohio, and by Angelin.

De Koninck and Le Hon[†] figure a stem joint of Poteriocrinus showing the same structure of the axial part of the stem which we find in the upper joints of Calamocrinus.

In the descriptions and figures of Crinoids given by Hall and Whitfield of the Crinoids of the Waverly group (Geol. Survey of Ohio, Palæontology, Vol. II. Plate XI.), the upper part of the column of Actinocrinus consists of alternating or of uniform joints, soon passing into a region of the column in which the joints are alternately thick and thin, and rapidly passing to thick joints separated by three or four thinner joints, which in their turn may be wide or narrow, the thicker joints projecting beyond the edge of the column.

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[*] Palæontology of New York, Vol. II. Plate 42, Figs. 7, 7c.
[†] De Koninck and Le Hon. Crinoïdes du Terrain Carbonifère de la Belgique, 1854, Plate I. Fig. 1.

In Platycrinus the upper part of the stem is also made up of alternating thick and thin joints.

In Forbesiocrinus the upper part of the column is widest, gradually tapering, and made up of thin flat disks, passing into the stem with alternating thick and thin disks.

Hall figures, on Plate A 41 of the second volume of the Palæontology of New York, the calyx and upper stem joints of Closterocrinus elongatus. The upper part of the column is spreading, and the upper face of the top stem joint is conical, much as we find it in some of the Apiocrinidæ.

On Plate 42, Fig. 7 c. Hall also figures the expanding upper part of the column of Dendrocrinus longidactylus, showing the young intercalated joints, the outer faces of some of which have found their way to the surface of the column.

In Ichthyocrinus lævis, the infrabasals, " undeveloped pelvic plates surrounding the centre " as Hall calls them, resting upon the column, are figured on Plate 43, Figs. 2 f, 2 g, much as in a species of Glyptocrinus sent me by Wachsmuth for examination. The spreading upper part of the stem of Ichthyocrinus is made up of thin flat joints, which gradually taper into thicker joints.

In Lyriocrinus the joints are alternately thick and thin (Hall. Pal. of New York, Vol. II. Plate 44); also in Lecanocrinus (Plate 45). In the spreading upper part of the stem of Saccocrinus (Ibid., Plate 46), the alternating joints are thick and thin, the former ornamented with a line of granules, the latter smooth. In Caryocrinus the stem joints are nearly of the same thickness, alternating irregularly wide or narrow (Ibid., Plates 49, 50).

In Homocrinus figured by Hall (Ibid., Vol. III. Plate 1, Fig. 8), the upper part of the stem adjoining the calyx shows a few thin joints slightly wider than the lower part of the column, in which the wide joints projecting beyond the general outline of the column are separated by from three to four slightly thinner joints (Plate 1, Fig. 5 a).

The upper part of the column of Mariacrinus nobilissimus (Ibid., **Plate 2,** Fig. 1) is composed of thin uniform joints, while in Mariacrinus pachydactylus (Plate 3, Fig. 1) the upper end of the column consists of thicker joints, and the column widens gradually towards the lower part of the stem; though from the figures given by Hall in Plate 3 B it is evident that towards the extremity of the stem it tapers again and gives off numerous branchlets,

the main stem itself gradually becoming reduced to the size of one of the branchlets, much as in Rhizocrinus. The column of this genus is noted for its large axial canal.

In some of the figures given by Meek of the stem of the same genus, a few of the upper stem joints appear to be somewhat thinner than the others, while in other cases thick and thin joints alternate (Geol. Survey of Ohio, Palæontol., Vol. I. Plate 1).

In the upper part of the stem of Heterocrinus, according to the figures given by Meek and Worthen, the flat joints of uniform height taper quite rapidly (Geol. Survey of Ill., Vol. III. Plate 4).

In the second volume of the Geological Survey of Illinois, Meek and Worthen figure the upper part of the stem of Onychocrinus as made up of very thin flat joints, the stem tapering quite rapidly and being composed of flattened joints of greater height (Plate 17, Figs. 3, 7).

The column of Glyptocrinus consists of alternately thick and thinner pieces, the former projecting beyond the latter.

Meek has also figured * the upper part of the column of an interesting specimen of Heterocrinus juvenis, in which young joints are intercalated between every two of the older joints. Of these he says, " Column . . . composed of moderately thin disks, between each two of which are intercalated, for some distance below the body, five small pieces, ranging exactly on lines with, and corresponding in size and form to, the subbasal pieces at the connection of the body with the column; *further down these intercalated pieces seem to coalesce and form disks like the others.*" †

In a fine stem of Megistocrinus nobilis, W. & S. (Geol. Survey of Ill., Vol. VIII. Plate XVI. Fig. 6), the rings alternate from the very top, with projecting and receding joints. The same is the case in the stem of Dorocrinus (Vol. VIII. Plate XVII. Fig. 6), while the upper part of the stem of Actinocrinus Arnoldi, W. & S. (Plate XVII. Fig. 10), is made up of joints with angular sides, nearly of the same diameter, slightly tapering from the top.

In some other species of Poteriocrinus, P. occidentalis (Geol. Survey of Ill., Vol. VII., Plate XXVII. Fig. 2) and P. coxanus (Fig. 1), the upper part of the stem, made up of uniform joints, very soon passes into a structure made up of narrow flat joints alternately higher and flatter.

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\* Geol. Survey of Ohio, Palæontology, Vol. I. Plate 1, Fig. 3 a.
† Ibid , Vol. I p. 11. The Italics are mine.

The stem of Zeacrinus coxanus has a very similar structure (Plate XXVIII. Fig. 1).

The stem of Dorycrinus mississippiensis, Roemer. figured by Wachsmuth and Springer (Geol. Survey of Ill., Vol. VIII. Plate XII. Fig. 4), has about fourteen or fifteen uniform joints followed by joints projecting beyond the outline of the column. separated by flat thin joints which gradually increase from one or two between successive joints to six or seven.

Poteriocrinus (Plate XII. Fig. 2) has a very wide stem at the top, gradually becoming smaller. and the joints placed closer together.

Batocrinus (Plate XV. Fig. 4) has a stem with large joints. gradually passing to a closely packed column; at the top there appear to be some new joints.

Figures of Taxocrinus Fletcheri. Worthen (Plate XV. Figs. 6, 9). show stems tapering very gradually from the top, made up of closely packed flat joints, gradually increasing in height, and passing into larger joints projecting beyond the outline, and separated by one flat joint of less height and of a less diameter.

In Toxocrinus polydactylus. figured by McCoy (Carbonif. Fossils of Ireland, Plate XXVI.), the upper part of the stem is composed of about twenty thin joints of greater diameter than those below it. (The upper part of the column is suddenly dilated.)

Wachsmuth and Springer figure (Geol. Survey of Ill., Plate XV. Vol. VIII.) tapering stems of Batocrinus and of Platycrinus. They also figure on the same plate the upper part of the stem of Taxocrinus. showing the upper joints of the stem to be closely packed, and flat compared with those of the lower part of the stem.

Tapering joints do not necessarily mean a free existence. as Carpenter has noticed when speaking of Eucalyptocrinus, Hall,[*] which has a spreading root.

Pentacrinus decorus has when young a well marked tapering stem.  See Chall. Rep.. Plate XXXV. Fig. 1. showing a young stem of 60 mm.

Miller [†] has figured Dendrocrinus and Glyptocrinus. which evidently were free; the column of the former long and tapering, that of the latter often found wound round other objects by means of an extremely flexible column.

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[*] Twenty-eighth Ann. Rep. New York State Mus. of Nat. Hist., 1879, Plate XVII. Fig. 5.

[†] A. S. Miller, Cincinnati Journ. of Nat. Hist., Vol. III. p. 233, Plate VII., 1880.

The great increase in the dimension of the column of certain Crinoids at its upper extremity, forming as it were a prolongation of the cup of the Crinoid gradually passing into the stem, is an interesting structural character. It dates back to some of the Cystideans, in which the upper extremity of the stem is far more closely connected with the plates of the cup than is the case in Crinoids proper.

In the Cystidean stems figured by Hall in the Palæontology of New York, there are also many cases to show that young joints are intercalated in the upper part of the stem between the older ones.

How different the stem of some of the Cystideans is from that of the other Crinoids is best illustrated by the structure of the upper part of the stem of Dendrocystites,* in which the plates of the test form a pouch which gradually passes into a regular crinoidal stem. Neumayer† considers this type of stem as the primordial form.

The base of the column of Cystids is remarkable for its peculiar structure and shape. The upper part, where new joints appear, consists of joints quite similar to those of the true Crinoids, but the lower part is somewhat club-shaped (Hall, Palæontol. of New York, Vol. III. Plate 7. Figs. 5, 6, 14–16, 20–22). The axial cavity of this part of the column is large.

That the pentagonal stems hold a definite relation to the calyx has been clearly shown by Wachsmuth and Springer,‡ and goes far to prove that the stems must originally have had a far more intimate connection with the calyx than its representatives of to-day have; and the fact that in a number of palæozoic Crinoids the axial canal is very wide compared with that of recent types seems to indicate an additional function to that of the axial canal, which, as Neumayer suggests, we cannot explain from the recent representatives.

The large size of the axial opening in Mariacrinus would seem to indicate other uses for it than merely the protection of the axial cords. See Hall, Palæontol. of N. Y., Vol. III. Plate 3 B. Hall's Figure 2 indicates a communication between the main axial cavity of the column and the rootlets.

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* Barrande, Syst. Sil., Vol. VII. Plates 26 and 27. Billings has also given very fine figures of stems of Cystideans (Plumocystites, Canad. Geol. Survey, Decade 3, Plate I.), showing the great size of the base of the stem.

† Is not the loss of the stem in the Comatulæ, as suggested by Neumayer, foreshadowed already among Cystideans, in which many of them have a stem which gradually tapers, so that it could be of use for only the slightest possible attachment, and finally frequently is present as a mere shrivelled wart-like appendage?

‡ Proc. Acad. Nat. Sci. Phila., 1885, p. 229.

Griffith * figures a remarkable widening of the stem of a specimen of Toxocrinus (Plate XXVI. Fig. 7), which reminds us of the analogous structure in the Cystids.

## STRUCTURE OF THE STEM.

Dr. W. B. Carpenter † has figured the structure of the stem of Pentacrinus caput-Medusæ, of Pentacrinites briareus, and of another undetermined species of Pentacrinus.

There are also to be found in the older works of Goldfuss, Quenstedt, Bronn, Zittel, and other palæontological memoirs, a number of figures showing the structural details of the joints of the stem and arms of Crinoids. The reticulation of the limestone plates and joints is remarkably uniform in all Echinoderms, showing but little variation, the reticulation, as has been suggested by Zittel, closely resembling that of the Hexactinellidan Sponges.

Dittmar ‡ has figured the stem of a new genus, Porocrinus, in which there are in the stem a large number of fine canals running longitudinally, with a trend towards the exterior, to which lead a number of lateral canals situated in the space between the joints. Although Dittmar says distinctly " statt eines einzigen centralen Nahrungskanal, sehr viele feine runde Kanäle vorhanden sind," yet further on he says " der centrale Kanal allein zeigt keine seitliche Abzweigung "; and the longitudinal section which he gives shows a central canal (p. 393, Fig. 3). The figure he gives of the surface connecting two joints does not differ from that seen in Calamocrinus, where we find a large number of radiating lamellæ, but they alternate with those of the adjacent joint, and lap, and do not correspond, as he says, to leave room for the lateral canals. He has noticed the great irregularity in the intercalation of new lamellæ, and this agrees fully with the development, as I have traced it, in the young joints of Calamocrinus. We find in the joints of Calamocrinus (Plate XXV. Fig. 9) the same parabolic arrangement of the limestone cells of which he speaks, but the interstices do not form such regular canals as he describes. He considers the canals as analogous in function to the " Sehnen " of Müller.

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* A Synopsis of the Characters of the Carboniferous Limestone of Ireland, 1844

† Report on the Microscopic Structure of Shells, Part II., Sect. 120, Figs 74-77   Report of the Seventeenth Meeting of the Brit. Assoc. for the Adv of Science, held at Oxford, June, 1847, London, 1848.

‡ Alphons von Dittmar, Zur Fauna der Hallstädter Kalke, 1866, in Benecke, Geog. Pal. Beiträge, Vol I.

Fraas [*] has given a section of the stem of Millericrinus, showing (Plate XXIX. Fig. 12) the modifications introduced into the arrangement of the original limestone network by the longitudinal muscular threads. These give rise on the faces of the joints of the Crinoid stem to a very varied arrangement of the calcareous cells which have considerable systematic value.

I have on Plate XXVII. given views of the minute structure of the pinnules, of an arm joint, of the first radial, and of a part of the stem. The close agreement of the limestone network is apparent at a glance. Figure 3 shows the structure of the meshwork, the closeness of the reticulation depending mainly either upon the size of the meshes or of that of the connecting rods. In the pinnules and arm joints the reticulation is in curved lines diverging from the axial canal of the pinnule or arm joints (Figs. 1, 2). In the radials it is in straight lines, at right angles nearly to the outer face, where the reticulation is coarser (Fig. 4). A longitudinal section of the stem through one of the joints shows the vertical arrangement of the limestone cells around the axis (Fig. 5), while a transverse section (Fig. 6) shows the radiating arrangement of the reticulation from the edge of the joint to the central canal. The darker spots of the limestone network represent the cross sections of the rods at right angles to the plane of the section connecting superposed cells.

## THE APICAL SYSTEM OF ECHINODERMS.

As Neumayer [†] has pointed out, the difficulty of comparing the apical system of Echinoderms with the monocyclic or dicyclic Crinoids introduces at once difficulties which have given rise to many different opinions.

In making the comparisons of the apical systems of Echini, Starfishes, Ophiurans, and Crinoids, it has been customary to ignore the Holothurians, and only the papers of Theel, of Semon, and of the Sarasins have given us any grounds for not considering the Cystideans as the earliest stage of Echinoderms.

Starting from the assumption that the Crinoids represent this earliest phase of Echinoderm development, it has been customary to homologize

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[*] Eberhard Fraas, Die Asterien d. Weissen Juras von Schwaben u. Franken. Paläontograph., XXXII., p. 237.

[†] Morphologische Studien über fossile Echinodermen. Sitzungsb. d. k. Akad. der Wiss., LXXXIV., I. Abtheil, Juni Heft, 1881, p. 113.

the plates of the apical system of the Antedon larva with those of the same system in the other orders of Echinoderms excepting the Holothurians. Allman,* who was the first to make a detailed comparison of the pre-brachial stage of Comatula with some of the extinct Crinoids, recognized in the calyx and top stem joint of the young Comatula the centrodorsal plate of the adult Comatula, the basals as they are found in the moncyclic Crinoids, the radials, and the interradials (orals).

The homologies of the orals of the embryo Antedon with those of the genera, both recent and fossil, in which they occur, are more easily recognized, and may for the present be left out of the discussion, referring only to such palæozoic genera as Coccocrinus, Haplocrinus, Pisocrinus, or to the recent Holopus, Hyocrinus, and Rhizocrinus.†

In my first attempt to homologize the plates of the embryo Starfish with those of the Echini and Crinoids, in 1864,‡ I compared the dorsocentral plate with the basal plate of Crinoids, the five plates in the angles of the arms with the interradial plates (not the interradial plates as now understood by writers on Crinoids), and the arm plates with the radial plates of a Crinoid. The dorsocentral plate I considered therefore as the homologue of the solidified basalia. In this view I was followed by Lovén, who in 1871 § regarded the single central disk in the young Echinoids as homologous with that of Marsupites, the five genital pieces to be regarded as basalia (infrabasals), and the five ocular as radialia (basals). This Lovén expanded more fully in 1874 in his " Études sur les Échinoïdées." Lovén, struck by the peculiar striation existing in the plates of the apical system of young Echinidæ and of the Saleniæ, and by the existence in those stages of a large central plate, was induced to make a more detailed comparison of the apical plates of the Sea-urchins with the Crinoids than had already been made between Starfishes and Crinoids,‖ and chose for his term of comparison Marsupites.¶ Lovén does not seem to have seen at that time my original paper on the Embryology of the Starfish, nor that on the

* Trans. Roy. Soc. of Edinb., Vol. XXIII., 1863, p. 241.

† Carpenter mentions Rhizocrinus Rawsoni as having been dredged off Panama by Captain Cole of the telegraph steamer " Investigator." Thinking there must be a confusion of labels, — for the " Investigator " was stationed only in the Caribbean, — I applied to Professor F. J. Bell, who kindly informed me that the locality should read " Off Colon " (State of Panama).

‡ Embryology of the Starfish, p. 50

§ Öfversigt af K. Vetenskaps-Akad. Förhandlingar, 1871, No. 8.

‖ Embryology of the Starfish, p. 62.

¶ P. H. Carpenter has plainly shown this comparison of Lovén to be untenable, Quart. Journ. Micr. Sci., XVIII., New Ser., p. 357.

Embryology of Echinoderms, both published in 1864, though he quotes the title of the last memoir; for he makes no allusion to my description of the central anal plate in young Echinoids in 1864, except in connection with my paper on the young stages of Sea-urchins in the Preliminary Report on the Echini dredged by Mr. Pourtalès[*] between Florida and Cuba. Nor does Lovén, while discussing the homologies of the dorsal plates of several young stages of Asterias glacialis, refer in any way to the descriptions and figures given in the "Embryology of the Starfish" of the early stages of Asteracanthion.

In 1872 Beyrich[†] concludes an article on the basis of the Crinoidea brachiata with suggestions on the analogies of the peculiar subdivision of the basis of the Crinoids and the symmetrical structure of other Echinoderms, especially Sea-urchins. He says the radials and interradials of Crinoids correspond to the ambulacra and interambulacra of the Sea-urchins, and, further, that the radials of Sea-urchins, as in the Crinoids, do not unite at the dorsal pole, but are separated by the apical system (Scheitelapparat), which from its position is analogous to the basis of the Crinoids. He also calls attention to the fact that in the symmetrical Sea-urchins one of the interradials is specialized above the others by the presence of the anus, dividing the test symmetrically by an anal axis, as in the Crinoids. He also says that in the composition of the apical system of the Sea-urchins we find no analogue to the deviation of the regular pentagonal subdivision of the basis of the Crinoids.

Müller in 1854 also already foreshadows the apical homologies of the Echinoderms. He says: "Der Kelch eines . . . Echinosphærites, Echinoencrinus sei der Apex eines Seeigels, er ist jedoch eine solche Ausdehnung des Apex, welche die sämmtlichen Eingeweide des Thiers umfasst." [‡]

In the comparison which I made between the plates of the young Starfish and those of a Crinoid, I spoke of the central plate as present in both, and called attention to the absence of homology between plates which constitute the bulk of the apical system in the young stages of the Starfish and Crinoid, homologizing the genitals of the young Starfish (the interradials,[§] as I called them) with the basals of Allman's Antedon stage.

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[*] Bull. Mus. Comp. Zool., Vol. I. No. 9, 1869.

[†] Monatsber. d. K. Akad. d. Wiss. Berlin, Feb. 9, 1871, p. 54.

[‡] Müller, Bau der Echinodermen, 1854, p. 14.

[§] But I had no intention of comparing them to what have been called interradials or calyx interradials in palæozoic Crinoids. I merely intended to state that they were plates having an interradial position.

The difficulties introduced by Lovén and by myself* in our both attempting in a different way to find the homologues of the plates of the Crinoids, one from the monocyclic and the other from the dicyclic type, have been happily solved by Carpenter,† who pointed out that the true homologies consisted in always comparing plates radially or interradially situated; that the first basals of Lovén's terminology were radials, the second interradials; and that naturally the genitals of Echini, being interradial, could not be homologous to the first parabasals, but must be homologous to the second parabasals.

Carpenter has clearly shown the confusion which arose in the nomenclature of the basis and parabasals from the supposition of Müller that the basals must always rest on the uppermost stem segment.

It thus becomes clear that the interradially placed basals of monocyclic Crinoids, the genitals of Echini, the first ring of interradial (referring to their position only) plates in the young Starfishes and the young Ophiurans are homologous.

We have a central plate in the embryo Starfish, Ophiuran, Sea-urchin,

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* In the earlier attempts to homologize the apical system of Echini with the Crinoids, both Lovén and I committed the same mistake which Muller made in looking upon the plates occupying the ring next to the stem as the *basis*.

Carpenter did not seem to realize that in 1881 there was but little uniformity in the nomenclature of the plates of Crinoids; and the very fact that in Comatula the basals undergo considerable metamorphosis to form the rosette went far to convince me that such a coalescence of the basals was not unnatural.

Zittel speaks of the central plate of Marsupites and of Agassizocrinus (which is within the ring of infrabasals) as the homologue of the centrodorsal of the young Comatula and the odd central plate of the apical system of Echini. He also suggests that the centrodorsal plate of Apiocrinus, with its five radially placed edges, on the top of the upper stem joint, is a coalesced infrabasal.

Johannes Walther says (Untersuchungen über den Bau der Crinoiden. Palæontographica, XXXII., 1886, p. 156) that under certain illumination the *centrodorsal* shows traces of radial sutures: "in die einspringenden Winkel lenken die 5 Basalia ein."

We cannot follow Walther in his estimate of the value of the vertical sliding of a morphological plane from a lower to a higher horizon, in order to account for the formation of the dicyclic bases of Crinoids from the monocyclic. The oldest known Crinoids have a dicyclic basis, and there is nothing in the development of Antedon to show from the observations of Bury, who discovered the presence of embryonic infrabasals, that the infrabasals are not resorbed; while, on the contrary, the monocyclic Crinoids are of later origin than the dicyclic, and this is supported by palæontological evidence. What he says of the impossibility of the formation of the infrabasals from the upper stem joint need not be discussed, in view of the facts here presented of the nature of the pentagonally lobed body found on the top of the upper stem joint in Calamocrinus.

All attempts at homologies based upon the comparison of structural features of one class of the animal kingdom with those of another can only tend to increase the existing confusion, and Walther's attempt to determine the position of his imaginary axis from the position of the anal opening and the course of the alimentary canal is at variance with all our present ideas of Echinoderm morphology.

† On the Oral and Apical Systems of Echinoderms, Quart. Journ. Micr. Sci., XVIII., 1878. p. 351.

and Crinoid, but the ultimate result of the development of the plates of this central area is very different in the Sea-urchins and Crinoids from what it is in the Starfishes and Ophiurans, in which the central plate remains single.*

And again we have in the embryo Echinoderms the radially placed ocular plates of Echini, terminal plates of Ophiurans and of Starfishes, and the radials of the Crinoids, which form in these (except in the Ophiurans) the distal ring around the central plate. But here again modifications are introduced during growth in the different orders which complicate the question of the homology of these parts. In the young Sea-urchin the central area is — no matter what its position may be in the adult, which is covered by a greater or smaller number of plates — occupied by the anal system, and in a large number of genera the anal system is covered by a single plate.

In the Crinoids the central area is occupied by a stem or its representative, and it seems to me more natural to homologize this central area of the Echini and of the Crinoids than to attempt, as has been done, to pick out a single anal plate of the Echini which does not exist in many recent families, and probably not in many fossil types, and homologize it with the central plate of Starfishes or of Ophiurans and the terminal plate of the stem of the larval Comatulæ, as has been done by Carpenter.

In the genital ring even, there are difficulties in the way of a strict homology of the basals of Crinoids and of the genitals of Starfishes and Ophiurans.

Carpenter† has figured diagrammatically the disks of a large number of Ophiurans, in which he thinks he has discovered the infrabasals of the dicyclic Crinoid. The regular arrangement of the plates of the central disk of Ophiurans has been observed by all writers who have dissected Ophiurans, and they have spoken of the apical rosette, and of its similarity to the arrangement of the plates of the crinoidal calyx. Sladen has also carried the comparison of the abactinal plates of the Starfish somewhat further than his predecessor, Lovén, and looks upon the ring of plates between the

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* Ludwig truly says (Zur Entwickelungsgeschichte des Ophiurenskelettes), "Erscheinen überall im Bereiche des dorsalen Scheibenperisoms neue Intermediärplatten zwischen und neben den einmal gebildeten sich anlegen zu können." Ludwig was the first to show that the terminalia in Ophiurans became separated, as those of the Starfishes, from the central disk by the intercalation of additional radial plates. Some of these Carpenter interpreted as representing the infrabasals of Crinoids.

† Quart. Journ. Micr. Sci . Vol. XXIV. p. 1, January, 1884.

basals and the dorsocentral as representing the infrabasals. When, however, we remember that in one and the same genus in Ophiurans we may have infrabasals present or absent, and that in closely allied Starfishes there may be two or even three rings of plates developed in addition to the ring of plates called infrabasals by Sladen, it looks as if he and Carpenter had carried their homologies too far. I will grant that we have rings of plates between the basals and the dorsocentral, the first of which next to the basals may be called the infrabasal ring; but what shall we call the others? Is it not more natural to look upon the successive rings of plates found in Ophiurans, Starfishes, and Echini, not as strictly homologous, but as representing an earlier echinodermal stage? For in the Cystideans, Holothurians, and in some Crinoids, where the plates of the test are merely so many rings of plates following one another next to the dorsocentral, we cannot compare in greater detail the plates of the second or third ring to the single ring of plates corresponding to them in the monocyclic Crinoids.

As Carpenter himself says, "The manner in which these plates vary, both in position and in development, within the limits of a single genus, is very remarkable." In the species of Ophiomusium he names, the plates agree fairly well, while in Ophiozona there is a great variation. One of the species described by Ludwig* shows perhaps better than any other that the successive cycles of plates soon become irregular, and have no special meaning.

Furthermore, it should not be forgotten that the homologies of the primary plates are greatly confused from the fact that the corresponding plates in the different orders of Echinoderms do not appear at the same period of growth in each, and that the same differences in time exist even in species of the same genus.

The central system, if I may call the stems of the Crinoids or their homologues by that name, is in the Crinoids partly separated from the basals by one ring of radially placed infrabasals. In the Ophiurans and Starfishes the central plate may be separated from the basals by a number of such rings, forming the upper surface of the disk, which with the central plate correspond to the central system. The plates covering the central system are developed horizontally only in the Echini, Starfishes, and Ophi-

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* See his figure of Ophioglypha maculata, Plate VI. Fig. 12, Echinod. d. Beringsmeeres, Zool. Jahrbucher. I.

urans, while in the Crinoids they are developed vertically to constitute
a stem or its homologue. In the Holothurians this central system is reduced
to a minimum. In the Starfishes and Ophiurans the central system is
not limited to a circumscribed area, as in the Echini or Crinoids. In Echini
it is limited to the anal system, in Crinoids to the stem; in Starfishes and
Ophiurans it includes all the plates of the upper and lower surface of the
disk which are neither the original genitals nor the terminals, and which
do not belong to the ambulacral system.

This view would restrict the homology of the first formed plates of em-
bryo Echinoderms, and leave us to deal with general modes of development
diverging very rapidly in very distinct directions from such a generalized
Echinoderm embryo as we may recognize.

The mode of formation of new segments is totally unlike in the arms of
Crinoids from the manner in which additional abactinal plates are formed
in Ophiurans and Starfishes. New plates are formed by the forking of the
terminal joint, one of the joints developing into a pinnule, the other form-
ing the extremity of the arm, and forking again after a time to repeat the
same process.

Although the mode of growth of the ambulacral system is the same in
the Ophiurans, Starfishes, Echini, and Crinoids, new tentacles being inter-
calated at the base of the primitive terminal ones, yet the position of the
terminals in the Ophiurans and Starfishes is very different in the adult
from what we find it in the very young stages, while in the Echini it has
not materially changed, and there is no plate occupying such a position
in the Crinoids.

In the Crinoids the interradial plates are developed between the orals
and the basals, and the basals are as much an interradial plate as any
other, even if the name interradial has received a more limited application.

In 1864, while studying the embryology of Echinoderms,* I discovered
that in the young Echinus, soon after the resorption of the pluteus, the
anal system was only covered by one large plate, that the anus opened on
one side of this, and that smaller additional plates were added at the anal
edge; and I subsequently showed that in many genera this original anal
plate could still be distinguished in the adult, although its prominence had
been greatly diminished by the increase in number and size of the other
plates covering the anal system. I compared this anal plate with the sur-

* Embryology of Echinoderms, Mem. Am. Acad., IX., 1864.

anal plate of the Saleniæ, which I considered to have retained in the adult
stages a feature only found in the embryos of the Echinidæ proper.

From a re-examination of the subject, I am now more inclined to look upon
the plates of the young of the Echinidæ, and the suranal plate of Salenia, not
as an embryonic feature, but as the remnant of the anal plates which have
gradually disappeared from the anal system through such genera as Acrosa-
lenia and Salenia. We unfortunately know but too little of the plates of the
anal system of the fossil genera, which, connected as they are by a thin mem-
brane, can naturally only be preserved under very exceptional circumstances.

Taking Bothriocidaris as an example of the oldest Sea-urchin known of
which the plates of the anal system are in part preserved, we find five
radials and five interradials, forming a single ring round the anal system.
At the angles of the radial plates five small anal plates are situated, sepa-
rated from one another by a smaller intercalated plate, thus forming an
outer anal ring of ten plates, the inner part of the anal system being evi-
dently covered by still smaller plates (Plate XXIX. Fig. I).

In geologically younger Sea-urchins, the Palæchinidæ, we have still a
single ring of radials and interradials enclosing the anal system, which has,
as in Bothriocidaris, an outer ring of ten anal plates and a second interior
ring of smaller plates, as in Palæchinus elegans (Plate XXIX. Fig. 2).

While it is true, as Neumayer says, that the apical system of the Palæ-
chinidæ, as far as the adult is concerned, presents no trace of the anal
plate so prominent in young Echinoids, and which is permanent in Salenia,
yet there is nothing to show that the young of those genera did not possess,
like the Euechinoidea, a single central anal plate in their earliest stages.
So that it seems as if the anal system of the Arbaciadæ, with their four
anal plates, was perhaps derived from that of Cidaridæ and Palæchinidæ.
There are a limited number of anal plates (eight) in Aspidodiadema Jacobyi
(Plate IX.ª Figs. 4, 13).*

I have often been puzzled how to interpret the many pores found on
the genital and ocular plates of the Palæchinidæ, such as are figured by
Roemer and by Meek and Worthen. On carefully reading the description
given by Schmidt† of the apical system of Bothriocidaris,‡ it becomes

* Report on the Echini of the "Blake." Mem. Mus. Comp. Zool., Vol. X. No. 1, 1883, by A. Agassiz.
† Mém. Acad. Imp. St. Pétersb., XXI., No. 11, 1874, p. 39.
‡ The structure of the test of Bothriocidaris is represented by the buccal system of Cidaris. One
range of interambulacral plates extending from the apex to the actinostome intercalated between rows
of ambulacra with two pairs of pores each. May not the double rows of later Palæchinidæ have
arisen by the opening out and the separation of the superposed plates?

evident that these so called pores are only perforated tubercles, or the pits left after the minute radioles have been broken off. The so called genital plates are not perforated, and the body which Schmidt calls madreporic can hardly be considered as such, as it is in the ambulacrum. (See also Plate XXIX. Fig. 1. of this Memoir.) But the apical system of B. globulus which he figures is evidently most irregular, and perhaps abnormal. Schmidt's description of the apical system of B. Pahleni does not agree with the figure which he gives on Plate IV. Fig. 1ᵇ, one of the smaller triangular apical interambulacral plates which separate the radial plates 1. 2, is not figured; though he speaks of five smaller triangular pieces, he figures only four.

In the figure given by de Koninck * of Palæchinus sphæricus, four of the genital plates are similar, eight-sided with three pores, and one seven-sided with only one pore; he could find no trace of the ocular plates. These I imagine must have been very diminutive. The apical part of the test which he figures shows at the apex only two rows of interambulacral plates in contact with the genital plates, occupying practically the same position as in the regular Echini; so that, owing to the shape of the plates, we have, as with them, one small and one large plate, the first plate being the youngest, and the next two forming obliquely the second tier. Next come three, and finally four rows, the second and third rows of interambulacral plates being interealated as it were between the outer rows, — an arrangement which is more or less distinct in genera with but four or five rows of interambulacra, but is difficult to trace where there are more. But they all agree in having one or two rows of interambulacral plates next to the apical and actinal systems.

In the figure given by Bailey † of the abactinal system of Palæchinus elegans (see also this Memoir, Plate XXIX. Fig. 2). three, or rather four, of the infrabasals may still be seen in their proper place.

I am astonished at the statement which Lovén makes regarding the structure of the interambulacra at the ambitus in Palæchinidæ. In none of the figures which he quotes is there such an arrangement at the actinostome as that he gives as characteristic of the order. Meek and Worthen's figure of Melonites (Palæont. of Ill., Vol. II. p. 227, Fig. 21) shows two and three plates. and their figure of Oligoporus (p. 248, Fig. 27) does not

* Bull. Acad. de Brux., XXVIII., p. 544, Plate, Fig. 1.
† Plate IV. Fig. B, Journal Royal Geol. Soc. of Ireland, Vol. I., New Series, 1861–67.

reach the ambitus. The figures of Pholidocidaris on Plate 15, Fig. 9, of Vol. V., are from specimens so badly crushed that the original arrangement can no longer be detected; and Hall's figures of Lepidechinus in the Geology of Iowa, Vol. I., Part 2, Plate IX. Fig. 10, show three or four plates at the actinal edge. I do not understand Lovén when he says,[*] speaking of the Palæchinidæ, that the adambulacral plates alone attain to the peristome and to the apical system, and I cannot agree with him when he gives this as a character of the order of Perischoechinidæ in his Études, p. 39.

Neumayer points out that in Cidaris coronata there are ten alternating plates forming two regular circles within the anal area, and nothing that is known of the youngest Cidaridæ indicates that this is not the normal number of plates; so that, if there has been a single anal plate in very young stages, it must have disappeared early.

If we examine other Echini still younger geologically, and pass to the Jura, we find in the Cidaris of those days an arrangement of the apical plates almost identical with that of the Palæchinidæ, — an arrangement which still exists among the Cidaridæ of to-day.[†]

In the young Cidaridæ there are five larger anal plates separating the ocular from the genital plates, and the central space is filled with minute plates. These five radial plates always retain their prominence in the full grown Cidaris, and have as good a right to be considered as infrabasals as the plates considered as such in the Ophiuridæ and Starfishes by Carpenter and Sladen. See Plate II. Figs. 2, 17, and Plate IV. Fig. 2, of my Report on the " Blake " Echini.[‡]

The anal plates in the Cidaridæ are not, as is stated by Carpenter, the remains of the central disk together with numerous secondary anal plates. There is nothing known to prove that in the Cidaridæ the anal system is not in the earliest stages covered by five plates, as in the Arbaciadæ it is covered by four, or in exceptional cases by five. We can scarcely speak of the subanal plates in young Echini as being in their primitive condition of " a fairly regular pentagonal shape." This can hardly be stated of any young Echinus I have had the opportunity to examine, (see sundry figures

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[*] Pourtalesia, p. 11.

[†] As, for instance, in Phyllacanthus baculosa (Plate XXIX. Fig. 7), in Goniocidaris geranioides (Fig. 6) and other species of Goniocidaris (Figs. 3, 4), and in several species of Dorocidaris (Figs. 8–12).

[‡] Mem. Mus. Comp. Zoöl., Vol. X. No. 1.

in the Revision of the Echini,) and yet the pentagonal shape is one Carpenter insists upon. See also Lovén's figures in his Études, Plates XVII. and XXI.

We may now examine the apical system of the young stages of some of the species of modern Cidaridæ, to see if it throws any light upon the probable way in which their anal system assumed its present structure, and incidentally how this corresponds to the so called archaic type of apical system of the Salenidæ and other Echinidæ.

In the young of a Dorocidaris papillata (Plate XXIX. Fig. 8) we find the interradial plates forming a closed ring, in the outside angle of which are placed the radial plates. The anal system is covered by five large plates projecting radially into the anal angles of adjoining interradial plates. We may assume that this is not an unusual structure among the young Cidaridæ, as Döderlein has figured the young of Goniocidaris biserialis (Fig. 3) and of Leiocidaris imperialis (Fig. 4) in stages but slightly older, and in which in one case one, and in the other two, additional anal plates had been formed to separate two of the radially placed plates, and form the beginning of an outer row of ten or more anal plates.

The youngest Cidaridæ figured by Döderlein * also show this disposition very clearly. See his Plate V. Fig. 8, and Plate IX. Fig 8 *a*, which show the apical system of a young Goniocidaris biserialis, 3 mm. in diameter, and of a small specimen of Leiocidaris imperialis, 4 mm. in diameter. New plates are formed, at first intercalated laterally, between the original five plates. The original five plates are readily recognized in the Cidaridæ. I would, in addition to the figures I have already quoted, add the following figures of Döderlein, in which this is very apparent : Plate II. Fig. 1, Stereocidaris grandis ; Plate III. Figs. 6, 11, S. japonica ; Plate IV. Figs. 11, 12, Porocidaris gracilis ; Plate V. Figs. 3, 10, 16, Goniocidaris biserialis ; Plate X. Figs. 4, 12, Eucidaris japonica.

This mode of intercalation of new plates, forcing their way from the interior to the periphery of the anal system, is continued as long as the anal system increases in size, and we can easily trace it even in the figures here given of the apical system of Goniocidaris geranioides (Plate XXIX. Fig. 6), of Dorocidaris Blakei (Fig. 11), of Porocidaris Sharreri (Fig. 5) ; and we see the same process going on in the formation of the second ring of anal plates in Dorocidaris Bartletti (Fig. 12).

* Die Japanischen Seeigel. I., Stuttgart, 1887.

What is especially interesting to note here is, that the first formed anal plates occupy a radial position; that is, they occupy the same position which the so called infrabasals do in Ophiurans and Starfishes according to Carpenter and Sladen. They are also within the ring of genital plates. This radial position the five original plates retain apparently, and they can still be traced in all the figures of Cidaridæ here given, in spite of the intercalated plates separating them, or in spite of the formation of a second, third, or fourth inner ring of anal plates. It is interesting to note that in the oldest Sea-urchins, both in Bothriocidaris and in Palæchinus, the position of five of the plates of the outer anal ring is radial, and we may fairly assume that they have been separated by a set of five other plates and an outer anal ring of ten plates formed very much after the manner described for the young Cidaridæ of to-day.

Owing to the irregularity in the development of the inner anal plates, the first outer ring does not always consist of the same number of plates. It varies greatly according to the time which the inner plates have required to reach the periphery.

In Dorocidaris papillata (Plate XXIX. Figs. 9, 10) we have an outer ring of anal plates consisting of ten plates. In Phyllacanthus baculosa (Fig. 7) we have eleven anal plates forming the outer ring, only one plate of the second ring having as yet found its way to the outer one; while in Dorocidaris Bartletti (Fig. 12) we find two plates separating the adjoining five radial anal plates. In Porocidaris Sharreri (Fig. 5) only two of the five radial anal plates are separated by two plates; and in Dorocidaris Blakei (Fig. 11) four of the radial anal plates are separated by two plates.

This has an important bearing on the number of the anal plates we find in the Aspidodiadematidæ and in the Echinothuriæ, in both of which families the genital and ocular plates form a single ring around the anal system, which varies from five to eight. See Figures 13–15 of Plate XXIX. In the case of Aspidodiadema tonsum (Fig. 13) it will be noticed that the five anal plates are placed radially. In the case of Aspidodiadema microtuberculatum there are two rings of anal plates, each of ten plates (Fig. 16).

We must also remember that the genital and the ocular plates of the oldest known Echini formed a single ring, practically on one level, and that it is only among more recent Echini that we find radially a considerable distance between the base of the anal edge of the genital ring and the tip of the intercalated oculars. In the recent representatives of the

older types, such as Cidaris,* Aspidodiadema, Phormosoma, and Asthenosoma, the plates of the two rings are (in Cidaris) often wedged apart by the plates of the anal system, or they form a single ring, the genital and ocular plates being in contact laterally (Aspidodiadema), or the genital and ocular plates may be widely separated by the intercalated anal plates (Phormosoma, Asthenosoma), while such types as some of the Salenidæ, in which only one of the oculars is in contact with the anal system, are intermediate with the typical recent groups of Desmosticha, such as Cœlopleurus, Podocidaris, Arbacia, Trigonocidaris, and most of the Echinidæ and Echinometradæ.

In the Echinothuriæ the number of anal plates in the outer ring is greatly increased, and it is not possible to fix accurately the position of the original five radial anal plates (see the figures of Asthenosoma hystrix, Plate XXX. Fig. 9, and of Phormosoma placenta, Fig. 8) except in one case. in one of the youngest specimens of Phormosoma I have had occasion to examine and to figure (Plate XXX. Fig. 12). See also Challenger Echini, Plate XII.ª Figs. 2, 7.

The only other Echini in which I have been able to trace the position of the five original radial anal plates are, first, Pleurechinus bothryoides (Plate XXXI. Fig. 6), in which they are very prominent, and separated by one interradial plate, forming together an outer anal ring of ten plates as regularly arranged as in the oldest Sea-urchins known. Next, those specimens of Arbaciadæ in which we find, as an exception to the general rule, the anal system covered by five radial anal plates, as in Arbacia Dufresnii (Plate XXX. Fig. 14) and A. nigra (Fig. 13), where we have only rarely either a larger or a smaller number of anal plates. The anal plates of Arbacia † in the youngest stages described appear simultaneously as far as we know, and this is probably also the case in Parasalenia gratiosa (Plate XXXI. Fig. 1).

In a specimen of Arbacia nigra from Talcahuano, measuring over three and a half inches in diameter, the anal system was composed of five large anal plates, four of them being much larger than the fifth. The inner

* Eocidaris of the Zechstein is undoubtedly to be considered as a Cidaris. Döderlein has called attention (Jap. Seeig., p. 45) to the peculiar bevelled sutures of the ambulacral with the interambulacral plates in this genus; this is such that we can hardly expect whole tests to be preserved. The structure of Eocidaris is in marked contrast to the imbricating of the plates of the test in Echinothuriæ and in the Palæchinidæ.

† Revision of the Echini, Fig. 68, p. 731.

points of the four larger plates were broken up into rectangular plates with rounded corners; so that we have in this specimen a second inner ring of smaller plates immediately around the anal opening (Plate XXX. Fig. 13). This arrangement of the anal plates gives to the anal system much the appearance of the anal system of Bothriocidaris, in which there is a ring of secondary plates within the large ring of anal plates.

This mode of breaking up of the anal system is different from that observed in the Echinidæ proper, in which additional anal plates are formed at one extremity of the anal system, or in that of the Cidaridæ, where the secondary series of plates encroach more or less upon the outer ring, and force their way between the plates of the primary ring. Where we have five anal plates covering the anal system, as is the case in some of the Arbaciadæ, these five plates occupy a radial position, as in Arbacia Dufresnii, though this is not the case in the specimens of Arbacia nigra with five anal plates.

In Podocidaris prionigera (Plate XXX. Fig. 11) there are five anal plates, but they are not radially placed. In the other species of Podocidaris there are only four plates, as in Podocidaris sculpta (Fig. 10), and as is usually the case in Arbacia and Cœlopleurus (Fig. 6). In one specimen of Cœlopleurus floridanus (Fig. 7) there were indications of the formation of eight anal plates by the splitting radially of the four original plates. The Arbaciadæ with only four anal plates we may consider as having one of the five radial plates atrophied. Bell mentions one specimen of Arbacia in which he found only three anal plates.

If we are to regard the existence of an anal ring of five, and subsequently of ten, anal plates as the oldest type of anal plating among the Echini, what we have seen taking place among the Cidaridæ and Arbaciadæ in the way of a reduction and variation in the number of plates of the outer anal ring may assist us in finding a true explanation for the apparently anomalous condition of things in the Salenidæ and in the young stages of many Echinidæ proper.

De Loriol has given a figure of the apical system of Acrosalenia, the precursor of Salenia, in which the greater part of the anal plates are preserved, and which, as has been noticed by previous authors, shows some affinity to that of the allied Cidaridæ (Plate XXX. Fig. 4). This interesting specimen seems to me to give the key to the apparently abnormal condition of the Salenidæ. In the specimen figured by de Loriol

we have an incomplete series of rings of anal plates, three larger plates with angular sides and fully as solid as the genitals and oculars, enclosing in the arc they form a set of plates gradually diminishing in size to the outer part of the anal ring, which was probably filled by still smaller plates.

All the plates of the anal system of Acrosalenia being thus irregularly arranged, it requires but a slight transition from this irregular arrangement of the smaller anal plates to a regular plating of a circular or elliptical anal opening flanked on two or three sides by three or four larger and more compact plates, to pass into the structural condition of the Salenidæ, where, owing to the atrophy of some of the large anal plates, the anal opening is flanked by only one large plate. This alone is closely joined to the genital ring, and seems to form a part of it, rather than of the anal system. In Acrosalenia we find a larger number of such plates, passing so gradually from the larger polygonal anal plates to the smaller irregularly shaped ones adjoining the anal opening, that there appears to be no question to which system of plates they all belong. That such a transition probably took place seems possible, if we compare the apical system of Salenia varispina, with its eight small anal plates (Plate XXX. Fig. 3) and its one large suranal plate, with the figures of the apical system of Salenia Pattersoni (Figs. 1, 2).

We may sometimes still detect a more or less indistinct trace of these original five radial plates by the presence of five larger plates in the outer anal ring, as in Toxopneustes variegatus (Plate XXXI. Figs. 8–10), in Trigonocidaris monolini (Fig. 5), Prionechinus sagittiger (Chall. Echini, Plate VI.[a] Fig. 13), or in Cottaldia forbesiana (Ibid., Fig. 16).

So that while we are undoubtedly justified in considering the single anal plate of the young of such Echini as Strongylocentrotus (Plate XXXI. Fig. 7), Trigonocidaris albida (Fig. 4), and Temnechinus (Fig. 3) as homologous with the single large anal plate of the Salenidæ, we are no longer justified in looking upon this kind of anal system with a single plate as the earliest type.* On the contrary, from the analysis that has preceded we

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* There is no Echinoid known, as the Sarasins seem to suggest, in which in the adult a single plate covers the anal system. Such a condition exists only in the youngest stages, and additional plates are intercalated between it and the genital ring, the first plate to appear remaining the most prominent during a part of the growth of the Urchin, while it always remains the most prominent in Salenia, and was already so in its youngest stages. To suppose, as the Sarasins do, that the large suranal plate may possibly be formed from the coalescing of a number of smaller anal plates, runs contrary to all

seem justified in looking upon the mode of formation of the plates of the anal system of the Salenidæ and of the Echinidæ proper as an atrophism of the primary mode of formation of these plates in the earliest known Sea-urchins. Only in the Echinidæ proper the plates of the anal system are not as it were separated into two categories, as in the Salenidæ, one of which seems to form a part of the genital ring (see Figures quoted above), while the other plates correspond to the smaller more or less irregularly arranged plates of the anal system in the Echinidæ. See the Figures of Echinus horridus (Plate XXXI. Fig. 11), of Toxopneustes variegatus (Figs. 8–10), and of Temnopleurus Reynaudi (Fig. 2).

Tiarechinus does not seem to me to have the great importance assigned to it by Lovén in tracing the homology of the calyx of Echinoids with that of the Crinoids. Judging merely from the description of the genus given by Neumayer* and Lovén,† I am more inclined to look upon this remarkable Sea-urchin as an eminently embryonic type, but possessing at the same time the unique character of having three rows of interambulacral plates, — a structural feature which it possesses in common with some of the Palæchinidæ, where there are five and seven interambulacral rows. Tiarechinus is closely allied to the earliest fossil representatives of the Arbaciadæ. The structure of the apical system is to my mind eminently Arbacia-like, and the spreading of the ambitus seems to be the first trace of the peculiar petaloid condition we find in the Arbaciadæ and Echinometradæ. Unfortunately, the anal plates are not preserved. To judge from analogy, I am inclined to look for a pyramid of four or five anal plates, as in the Arbaciadæ. No one can fail to see in the solid undivided apex a condition of things very similar to that presented in a young Arbacia such as I have figured in the Revision of the Echini, page 734.

The splitting of a tubercle in the suture of the interambulacral area is not a feature unknown among Echini. as Neumayer states. It is of common occurrence in the plates of the ambulacral system in the regular Echini (Desmosticha), and at the junction of the plates of the ambulacral and interambulacral systems, and is quite common in both the ambulacral and interambulacral areas in the Clypeastroids and especially the Spatangoids (Petalosticha).

that has thus far been observed regarding the development of the plates of the anal system. Existing anal plates may break up into a larger number, or additional plates may be formed by intercalation between the older ones, but no case has been observed in which they have coalesced.

  * Morpholog. Studien an Echinodermen.                           † Pourtalesia.

The faintness of the lines separating the apical plates of Tiarechinus, referred to by Lovén in his examinations of the original specimen described by Neumayer, is characteristic of all young Echini, and is well marked in the young of the Arbaciadæ. See my figures, and those of Garman and Colton.

Dr. Duncan,[*] fully recognizing the important features in the structure of the interambulacral areas, has established a new order for this genus, the Plesiocidaroida, which he places among the Palæechinoidea. This had also been suggested by Neumayer.[†]

Duncan in his Revision of the Echinoidea has also adopted for Echini the nomenclature proposed by Lovén for Crinoids. The adoption of a crinoidal nomenclature to designate the apical plates of the Starfishes, Sea-urchins. and Ophiurans seems to me open to very serious objections. While it is true that homologies may be more clearly indicated, yet we thus lose sight of the specialization which has taken place in each type, and the direction which the development of the orders has taken in palæontological time. We make less confusion for our successors by retaining within each order the special designations for the different plates, and homologizing to our heart's content; but in the present stage of the discussion, to adapt the nomenclature of the Pelmatozoa to the orders which are contrasted to them by the very adoption of the name Pelmatozoa adds nothing to the accuracy of our notions of the structure of the Echinoderms. We are taking it for granted that the Starfishes, Sea-urchins. and Ophiurans are the direct descendants of the Crinoids, — a proposition which, from our present knowledge of the fossil types. is only guesswork. We know as yet too little, not only of the homologies, but also of the structure, of the Cystideans to enable us to trace their development into either of the groups composing the Echinozoa, although they show in many directions affinities with the other groups of Echinoderms; and very ingenious hypotheses have been made [‡] to show how it would be possible for such forms as Mesites, found in the Lower Silurian of Russia, to pass on the one hand to the Asteriadæ, and on the other to the Echinidæ.

The study of fossil Ophiurans would, it seems to me, throw a good deal

* P. Martin Duncan, A Revision of the Genera and Great Groups of the Echinoidea, Journal of the Linnæan Society, XXIII., 1889.

† Die Stämme d. Thierreichs, 1889, p. 367.

‡ Neumayer, Morphol. Studien, p. 159.

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of light on the affinities of the Echinozoa; for the Ophiurans are in some ways the most crinoidal of the Echinozoa, and yet their affinities with the Starfishes on the one side and the Sea-urchins on the other are often striking.

When we examine the anal system in types in which it is disconnected from the apical system,* we find that the plates of the anal system of Discoidea are already quite spatangoidal in their arrangement. Cotteau figures those of three species of the genus; one in Échinides fossiles de l'Algérie (Plate XII. Fig. 2, p. 165, Cotteau, Peron et Gauthier, 5ᵐᵉ Fascicule. 1879); another in the Paléontologie Française (Vol. VII. Plate 1012, Fig. 6).

Cotteau has also figured the anal system of Discoidea cylindrica, (I copy here, Plate XXXII. Fig. 3, from the Rev. et Mag. de Zoöl., 1876, Plate I. Fig. 1,) in which the arrangement of the single ring of large plates enclosing a few smaller plates is quite complete.

Even in some of the Spatangoids, although the anal system is already disconnected from the genital ring, we can still trace the first outer anal ring made up of eleven plates, and in some cases of a second inner ring of plates. See, for instance, the plating of the anal system of Palæobrissus Hilgardi (Plate XXXII. Fig. 9), and that of a large number of Spatangoids, in which the plating is as regular as in any Cidarid, or that of Urechinus naresianus (Fig. 10) and of Cystechinus Wyvillii (Fig. 12).

In those Clypeastroids and Echinolamps (Plate XXXII. Fig. 6) in which the anal system has a small number of plates (not more than three or four), they may have taken their development as we have it in Echinarachnius parma, where, in very young specimens, the anal system has at first only one plate (Fig. 1), and later other plates are developed on each side of it (Fig. 2). A similar mode of development probably occurs also in Echinonëus (Fig. 4).

The same seems to be the case in the development of the plates of the anal system of Hemiaster (Plate XXXII. Fig. 11). In Echinocardium (Fig. 13) the central part of the anal system is covered by five plates,

* If Cystocidaris, Zitt. (Echinocystites, Thoms., non Hall) is really a Sea-urchin, we have the anal opening (?) placed, not in the apical system, but eccentrically (interradially), and closed with a pyramid of small plates, so that we might, as has been suggested by Neumayer, look upon the interradial position of the anal system in the regular Echini as an ancient character (Neumayer, Stämme d. Thierreichs, p. 380), which has appeared again after a long period of time with the Pygasteridæ in the Jura.

recalling the arrangement of the Arbaciadæ, surrounded however in addition by two other concentric rings of smaller plates; while in Neolampas we have an anal pyramid composed at first of five plates, and subsequently of eight (Figs. 7, 8). The number of plates of the anal pyramid of Palæostoma also varies from five* to seven.†

Of course there is the other and former point of view, that in the earlier types of Echini (Palæchinus and the like) the young also possessed a single suranal plate covering the anal system, and that this was transformed very early into a number of plates forming two or more concentric rings around the anal system. But the history of the plates of young Cidaris, one of the earliest of the Echinidæ to appear belonging to a type which has been most persistent from the Jura, and which still forms in our seas an important element in the echinoidal fauna, is decidedly opposed to this view. The young Cidaris has, as we have shown, five (infrabasals) radial plates, which divide laterally and form a first ring of ten or more plates adjoining the genital ring. We are therefore justified in assuming that in the Palæchinidæ there may have been in the young a similar radial system of five plates, and these would naturally form the structure which has been preserved in their anal system; so that we should be far more inclined to look upon the plates enclosed within the genital ring, such as are found in young Cidaris, as representing the primordial type of the Palæchinidæ, and that this type had gradually in geological time been modified so as to leave in Acrosalenia only three of the original five plates, in Salenia only one, exclusive of the smaller plates subsequently formed in the inner area enclosed by the five original plates. This degeneracy, so to speak, would account for the asymmetrical position of the plates in Acrosalenia and Salenia, as well as in the young of so many Echinidæ; so that we should no longer consider the apical system of Salenia and its representative at the present day in the apical systems of young stages of many Echini as reproducing the typical or original type of abactinal system from which all others have been derived. The present explanation of the homologies of the plates of the young Echinidæ and of Salenia has the advantage of being consistent with the palæontological development, while the former one has not.‡

* A. Agassiz, Revision of the Echini, Plate XXXIII. Fig. 14.

† Lovén, Pourtalesia, Plate XVI. Fig. 191.

‡ Neumayer appears justified in denying that the apical system of Salenia represents the typical stock from which the apical system of the recent Echinidæ has been derived.

## On some of the Homologies of Echinoderms.

I have not found it possible to discuss in the later of my publications on Echinoderms,* limited mainly to systematic work, many interesting points on their homologies which have been suggested by writers on Echinoderm morphology since the publication of my memoirs on the Embryology of Echinoderms in 1864. Owing to the republication of the greater part of one of these papers in 1874,† and of the other in 1877.‡ recent writers quote them as dating from the reprints, which thus appear as following the lead of naturalists whose results were published from five to seven years later. I mention this, not for the purpose of making any reclamation for the sake of priority, but to account for the anachronisms and contradictory assertions and opinions which have been attributed to me by writers who have either never seen the original memoirs I refer to, or who have not chosen to remember that their reprints represented work published thirteen years earlier. To those naturalists who deem it necessary that any criticism of their views should at once be noticed, I may seem to have acquiesced in the justice of their criticisms. It is one thing to meet new views with new observations; but merely to write an essay on an old subject for the sake of defending one's position has never seemed to me worth while. It does not particularly interest those who are not specialists in any branch that the views of A, B, or C should be quoted as frequently as they become modified in the pages of the next periodical to appear. To follow the researches of our fellow workers is a most grateful task; but no investigator should be expected to keep up with the daily vagaries, impressions, and endless changes . of front which must necessarily accompany any extended investigation, if they are to be published one day only to be contradicted the next.

The greatest caution should be exercised in carrying out the homologies of the different classes of Echinoderms into the minor details of the plates of the abactinal system. From the time of the Silurian we have had fossil Starfishes and Ophiurans differing but slightly from their congeners of the present day, and the development of the Crinoid, Starfish, and Ophiuran has been going on simultaneously from the earliest times, with but few of the so called transition forms belonging to the oldest

* Revision of the Echini, 1874 ; Challenger Echini, 1881 ; Blake Echini, 1883.
† Revision of the Echini.                          ‡ North American Starfishes.

strata, and none, at least among the Starfishes and Ophiurans, which would show any closer relationship to Crinoids than we find in our own time. From our present knowledge of palæontology, we certainly cannot assert that the Crinoids are the direct ancestors of the Starfishes, Ophiurans, or Echini, — leaving the relation of the Holothurians to them out of the question.

As far as the Echinoids are concerned, from the time of their appearance in the Lower Silurian they have constituted as distinct a class as they do to-day. We must look for the origin of the Echinoderms to Pre-Silurian times of which we have no record, unless a more careful study of the Cystideans may reveal among them affinities to the Echini and the Starfishes which are not suspected as yet. The Cystideans are the only group of Echinoderms which date far enough back to have preserved perhaps some of the transition types from which might have come the Starfishes, Ophiurans, and Sea-urchins.

Neumayer has well stated that there is nowhere in the younger formations a single transition form, and the appearance of such forms would go far to speak against a theory of descent, while all the transition forms we know are of such characters that we find no difficulty, as I have already noted for the Echini,* in tracing a quasi lineal succession.

In tracing the homologies among the order of Echinoderms, we are perhaps only comparing structures which have developed entirely independently in each of the orders of Echinoderms, and which, as Semon remarks, may be due to the similarity of the conditions imposed upon the early types by the modification of the ambulacral systems, and to the conditions imposed upon the development of the skeleton by the radial plan of growth.

The great irregularity we trace in the radial development of the plates of the few Cystideans we know may be a hint of the mode of development which has been followed independently in the other orders.† To argue from this, as has been done by Semon, that thus far

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* Palæontological and Embryological Development. An Address before the Am. Assoc. for Adv. of Science, August, 1880.

† It seems more natural to look upon the great difference and variability in the development of the calyx plates in the different orders of Echinoderms as depending to a great extent, as has been suggested by Carpenter (see Challenger Report, p. 172), on their relation to internal organs.

Wyville Thomson (On the Embryology of Antedon rosaceus, Trans. Royal Society. 1865) looked upon the modifications of the skeleton which characterize the principal divisions of Echinoderms as depending mainly upon the relative development or suppression of the radial and perisomic systems of plates.

we have neither palæontological nor embryological evidence that the Cystideans represented the primordial type of Echinoderms, does not appear to me to be sustained by the facts, any more than the statement that on embryological grounds we have far more reason to look upon the Holothurians as the representatives to-day of the most primitive type of Echinoderms.*

The assertion that the Holothurians were the stock from which the other Echinoderms were derived must always remain a sheer assumption. There is nothing thus far known of the embryology of that group which lends any support to that view; on the contrary, the primordial type of Echinoderms, as we may imagine it from their embryology, is a sac-like animal, with plates arranged irregularly, much as is the case in the Cystideans, with a simple ambulacral system arranged around a central opening. Such a semicystid embryo has been observed in Ophiurans, Starfishes, Echini, and Crinoids, and, with the addition of a larger number of limestone plates, is also represented in the Holothurians. See the young stages of Psolinus as figured by Kowalevsky and Metschnikoff, and of Cuvieria, of which I have figured the original Y-shaped rods.†

The Sarasins ‡ look upon the pentagonal arrangement of the plates and the ambulacra as a secondary structure due to the longitudinal nerves and muscles, the formation of rings of five or ten plates being due to the uniting of smaller irregularly arranged plates, analogous to the coalescence of primary ambulacral plates into large plates. This statement I do not understand, as original centres of calcification rarely anchylose except in older stages of growth.

The five perisomic oral plates in some species of Psolus are very similar to those of Hyocrinus; but the fact that they are replaced in some species by many plates instead of five by no means proves that they have coalesced. We look upon five as the original number of plates, which are developed in succession, and one of which may take a very great development and retain its prominence.

The Sarasins follow very much the same course of reasoning as Neumayer and Semon in speaking of the suranal plate of Salenia as a Crinoid

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* See Semon, R., Die Entwickelung der Synapta digitata u. die Stammesgeschichte der Echinodermen. Jenaische Zeitschr. f. Naturwiss., XXII., 1888.

† Embryology of the Echinoderms, 1864, Fig. 38.

‡ Paul und Fritz Sarasin, Ergebnisse naturwissenschaftlicher Forschungen auf Ceylon, Drittes Heft, 1888.

phantom. But they go further than Neumayer, who, with many others looks upon the Cystideans as the progenitors of Echinoderms, and so they look upon the Holothurians as the type from which the Cystideans, as well as the other orders of Echinoderms, have been developed. The similarity of some of the Psolidæ to stages of the armless Cystideans goes as far to prove the close relationship between the Holothurians and the Cystideans as the analogy between Echinoderm larvæ and Tornaria, the larva of Balano-glossus, which was so long mistaken by writers on Echinoderms for a Starfish larva, furnishes the ground for establishing a close relationship between the Worms and Echinoderms. The absence of a water system in Balano-glossus shows this similarity to be the most superficial analogy, and to be limited, as in echinodermal larvæ, to a distant resemblance in the arrange-ment of the vibratile cords, — a resemblance which had before misled older writers to look upon the Worms and Echinoderms as closely allied types.

Starting from the assumption, as he says, "Dass ihr [der Echino-dermen] Skelet niemals wirklich eine einheitliche Masse bildet," Semon loses sight of the very structural feature which is perhaps the most re-markable character of Echinoderms; namely, the manifest want of con-nection, I might almost say in every detail, of the internal organs with the exterior plates composing the test of the various orders of the class, and which was pointed out by Müller as early as 1854. Müller[*] has in-sisted upon the want of connection between the madreporic body and the apical plates. He has admirably expressed the want of connection existing between the internal organs and the calcareous plates, when he says: "Zur Zeit, wo der junge Seeigel selbständig wird und wo dieser Porus an ihn übergegangen ist, giebt es aber an dem Perisom des Seeigels noch gar keine Platten, weder Ambulacralplatten noch Interambulacral-platten noch Genitalplatten. Das Verhältniss zu den Platten ist daher überall secundär, . . . dagegen ist die Stelle des Porus in den Larven sowohl der Seeigel als Asterien und Holothurien überall dieselbe, auf dem Rücken der Larve seitwärts der Mittellinie."

I cannot understand the positive statement of Ludwig, "Dass bis jetzt auch nicht ein einziger Fall bekannt geworden wäre, in dem die Madre-porenöffnungen sich von den Genitalien entfernt hätten." In Echini the genitals may be entirely disconnected from the madreporic body in the Clypeastroids. We should from this alone question the homologies sug-

* Ueber den Bau der Echinodermen. Abhandl. d. K. Akad. d. Wiss. Berlin, 1854.

gested by Ludwig,* as they are based upon conditions found in the adult.
He has taken as his guide the position of the anus, which, as is well known,
does not hold a fixed position, but occupies an indefinite place, in the anal
system of Echini.   See the figures of the anal systems of a number of
Echini given by Lovén in his Études, and by myself in the Revision
of the Echini.†

Embryological investigations have proved beyond a doubt that the
plates which are called ocular, genital, madreporic, and anal in the Echini,
and genital and madreporic in the Starfishes and Ophiurans, have no or-
ganic connection with the genital or water systems.   The plates have
received the above denominations from being in early stages of growth
connected with the ocular,‡ genital, or water systems.   A similar want of
connection between the so called anal system and the anal opening, and
the shifting position of the madreporic body, has been traced by palæon-
tologists, and followed out in great detail by Lovén in his Études and
in his Pourtalesia.   The unstable position of the madreporic body, of the
genitals, and of the anal opening, for different periods in the palæon-
tological development of the Echini, had been insisted upon before him
by writers on the classification of recent Echini.

* Ueber den primären Steinkanal der Crinoiden nebst vergleichend anatomischen Bemerkungen
uber die Echinodermen überhaupt.   Zeitschr. f. Wiss. Zool., XXXIV.

† Carpenter (On some disputed Points in Echinoderm Morphology, Quart. Journ. Micr. Sci., July,
1880, XX. 321) has already called attention to the many difficulties in the way of adopting the new
homologies suggested by Ludwig.

‡ The nature of the odd terminal ambulacral tentacle of the young stage of Echinidæ has not been
investigated, so that no comparison of function can be made between it and the odd terminal tentacle
which carries an eye spot in the young Asteridæ.   A. Agassiz, Embryology of the Starfish, 1864.

These eyes persist in the old stages of the Starfish, and have been described by many authors since
the time of Ehrenberg (Ueber die Akalephen des Rothen Meeres), who first called attention to their
existence.

Forbes in his History of the British Starfishes (1841, p. 152) speaks of the perforations of the
smaller cordate plates which separate the ovarian plates as filled with a red membrane or substance,
and he regards them as analogous to the so called eyes of the Starfish.

Valentin says : "Je dois avouer que jusqu'à présent toutes mes tentatives pour découvrir une lentille
dans cet organe ont été vaines.   Je n'y ai trouvé qu'un corps pigmenté composé de différents tissus
fibreux et celluleux.   Une seule fois j'ai cru y découvrir, dans un exemplaire de l'E. lividus, con-
servé dans l'esprit de vin, un organe globuleux adhérant à une tige."   Anatomie du Genre Echinus,
1841, p. 100, Plate IX. Fig. 190.

It is exceedingly interesting to note that the only organs which may be called eyes which have as yet
been described in Echini should be placed on the surface of the test, either in continuous lines, or in
spots in the interambulacral areas, and that these so called eye spots should not be found on what echi-
nologists have been in the habit of calling ocular plates.   They exist on the genital plates and on some
of the plates of the anal system.   See for their description the careful investigations of the Sarasins, in
Ergebnisse naturwissenschaftlicher Forschungen auf Ceylon, von Dr. Paul Sarasin und Dr. Fritz
Sarasin, Erstes Heft, 1887.   Die Augen u. das Integument der Diadematiden, pp. 1-17, Pls. I.-III.

In studying the question of the homology of the hard parts of Echinoderms, we should take them as we find them, and not attempt first to build up a primordial type about which we know nothing, and which, according to our theory, must have had, or not have had, certain hard parts, and then build up homologies to be seriously taken with that type as a starting point. While dealing with parts which have, from all we now know, so slight a connection with the internal organs, it seems natural to give to the condition of the hard parts, as we find them in the fossils and also in the living types and their embryos of to-day, the principal weight in determining their affinity.

As a matter of course, the homologies established in the past have given way to homologies which, according to our standpoint, represent the existing state of knowledge ; and we must be prepared to see our pet homologies demolished with more accurate information. We need hardly discuss the opinion of Semon, who argues away the value of all homologies, on the ground that they naturally differ in accordance with our starting point.

It seems worse than useless to show up antiquated homologies, and print such glittering generalities as " Wie es mit diesen Thatsachen aussieht habe ich zu zeigen versucht, und kann mir wohl ersparen, noch andere, ganz in der Luft schwebende Homologien namhaft zu machen und zurückzuweisen " ! ! Semon closes by stating that " Die wahrscheinlichste Anschauung ist also die, dass die Stammform noch kein fest geordnetes Skelett besessen hat," that it may have possessed a circular support for the tentacles, and scattered plates, spiculæ, or wheels in the skin, and that with progressive radial development and thickening of the skin there was developed independently for each group of Echinoderms a type of skeleton. Semon is thus maintaining far more indefinite and unsubstantiated views, based upon conditions existing only in his speculations, than those reached by writers homologizing the hard parts of Echinoderms, structures which they find existing either in the fossil or living representatives. He is only on somewhat safer ground when he comes to express the view, long entertained by others, that such an irregular arrangement was to be found among Cystideans, and strengthens his position by repeating the well known fact, " dass keine Thatsache dafür spricht dass eine Klasse durch die andere Klasse hindurchgegangen ist," and that all this shows most emphatically that the different classes of Echinoderms have diverged in very early geological times.

12

When Semon says that we know nothing of the inner organization of the Cystidea, he is perfectly right; but to assume therefore that it is illogical to compare them in any way with the different primordial types from which both they and the other classes of Echinoderms may have descended, is another question. Even comparisons between existing types are far more logical than comparisons between imaginary primordial types with stages such as he figures as the Pentactula stages, not one of which is a true copy of what has been observed in nature.

We may remind those who do not see the grounds upon which homologies based upon comparison of the calycinal system are sustained, that a limited number of these hard parts are among the first structures to appear in the pluteus, and that they make their appearance much earlier than the structures upon which the opponents of these homologies base their conclusions. It is perfectly true that the development of the hard parts often becomes so far modified that it cannot be further followed. Still, the study of the hard parts, modified as they may be by their development in time and during growth, will always remain a fruitful field for speculation, based upon a more solid basis than homologies which call for ancestral forms of which we know nothing, or which represent later stages of development than those from which the calycinal homologies are drawn. While there are, and no doubt always will be, differences of opinion as to the interpretation of disputed points, that is no argument against the validity of the homologies as a whole. They at any rate have the great advantage of being based on facts, while the homologies based upon the assumption of a definite primitive ancestor representing one class are interesting speculations.

As yet no observations have been made carefully enough to show that the water canal of Holothurians occupies the same position which it does in other Echinoderm embryos. In Echini, Starfishes, Ophiurans, and Crinoids, it lies in the point of junction of the two extremities of the spiral water system. But, according to Semon, that is not the case in Synapta, and its position in the space between the third and fourth primary tentacles would go far to show that the primary tentacles are radial, and the secondary diverticula interradial; but no such interpretation can be given to Semon's figures of the position of the madreporic canal, as Bury and Hamann have both shown.

If, as Semon always insists, and with good reason, and as all echinolo-

gists are agreed, the different classes of Echinoderms have developed independently from the earliest fossiliferous times, this very fact presents the greatest difficulties we have to encounter at present in tracing back the earliest history of the Echinoderms; for, as shown by so many palæontologists, in the oldest of the fossiliferous beds we already find representatives of the different orders (of course excluding Holothurians) very highly specialized, and bringing us scarcely nearer to the primordial echinodermal type than we are to-day. With our partial knowledge of the fossils of those earlier times, we meet very much the same difficulties in tracing their homologies as in following those of their representatives of to-day.

May we not look upon the mouth tentacles of Holothurians as something peculiar to themselves, of which perhaps the gills of Echini and the Polian vesicles of Starfishes are the analogues, and not attempt a homology of parts situated radially in these classes of Echinoderms with parts the position of which is doubtful in Holothurians?

It is evident that to the pentactinal arrangement of the hard parts of the calyx of Echinoderms is due much of the analogous arrangement which we note among them; but it does not follow, because some of the plates which have been included by Carpenter and others in their homologies of Echinoderms do not belong there, that therefore some plates of the calyx of the different groups of Echinoderms are not to be homologized, and differences of opinion may possibly not be fatal to the value of the homologies.

I am surprised that Ludwig, after the attempts he has made to reverse the recognized homologies between the hard parts of Echini and Starfishes, should express such views as the following on the value of the homologies he has endeavored to establish: "Irgend welche unmittelbaren Beziehungen zu den inneren Organen des Thierkörpers sind, bei dieser lediglich auf die räumliche Anordnungsweise jener Platten gegründeten Homologisirung nicht in Betracht gezogen worden." He seems to have forgotten that he has based something of the strength of his former argument on the fact which had previously been made known by myself, and later by Goette, of the development of the actinal and abactinal systems from the two opposite water tubes of the pluteus stage.

We need further proof than that given by Bury's observations, which go counter to those of every other embryologist who has studied Echino-

derms, to satisfy us that the position of the abactinal system of the young Echinoderm is not limited to one of the water tubes.

It seems to me that the greatest difficulty in regarding the Holothurians as representing the primordial type of Echinoderms lies in the very fact so strongly emphasized by Semon himself, that the ambulacral tubes are interradial, as he considers them, and the primary tentacles radial. Unfortunately we know as yet no development of any Holothurian to show the manner in which the ambulacral tentacles are related to the ambulacral canal during their growth. Semon assumes the homology of the first primary tentacles of the Holothurians to the primary tentacles of other Echinoderm embryos, an assumption which is not recognized by other writers on the homologies of Echinoderms. Semon is mistaken in stating that the primary tentacles of the embryo Echinus disappear. They are retained in the genera which have been studied, namely, Strongylocentrotus, Arbacia,* Abatus,† and Brissopsis, so that the essential character

* The figure of a young Arbacia given in the Revision of the Echini (p. 735, Fig. 69) shows the odd terminal tentacle of the young Echinoderm as seen from the actinal side at the time when there are only three pairs of tentacles to each ambulacrum, and it is impossible to make out the arrangement of the coronal plates either in the ambitus or on the abactinal side.

Garman and Colton (Studies from Biol. Lab. of Johns Hopkins Univ., Vol. II. p. 247) give a figure (Plate XVIII. Fig. 9) of a young Arbacia in which the four anal plates are well developed, and five of the plates of the genital ring very faintly indicated. They seem never to have seen the Revision of the Echini, nor is there any reference made to the many figures given by Müller of the Mediterranean species; they refer merely to Fewkes's article in the Memoirs of the Peabody Academy, Vol. I. No. VI., 1881.

Fewkes (Proc. Bost. Soc. Nat. Hist., Vol. XXIV., 1888, p. 96) considers the primary spines of embryo Echinoderms as special organs representing the survivals of swimming organs in some problematical ancestral free swimming Echinoderm.

It is well known to all those who have used the pelagic fishing net, that not only young Arbacia, but the young of all Echinoderms developed from a pluteus, are free swimming for some time after the resorption of the pluteus. Young Starfishes and Ophiurans can float readily with the actinal surface upward for a considerable time, and young Echinoids similarly, with their gigantic tentacles swollen with water, present sufficient surface to float quite heavy tests. The floating of Starfishes, as also of young Holothurians, is due to the same cause. The use of the spines, as far as it is known among Echini, is for progression; and in Cœlopleurus, in Arbacia, in the Cidaridæ and Echinothuriæ, where they are specially developed, they are used for ambulatory purposes. The same is true of Ophiurans. The Comatulæ alone can swim, while Ophiurans use their arms in creeping. The reticular structure of the spines, allowing free absorption for water, would seem to adapt them far better for floats, as is the case in the appendages of Globigerinæ, for instance, than for primordial paddles. It is more natural to look upon these spatulate spines as due to the nature of the reticulation of the embryonic spines, which when it becomes excessively developed in a lateral direction would give rise to the flattened spines of certain Cidaridæ and Arbaciadæ, while when developing regularly they form more or less cylindrical radioles. Furthermore, none of the early types of Crinoids possess anything resembling these primordial swimming organs.

† In the young of Hemiaster cavernosus figured by Lovén, he shows the ocular plate perforated by the odd terminal tentacle (Pourtalesia, Plate XIV Figs. 164, 166), and from homology with the Starfishes it has been the custom to denote them as ocular plates.

upon which he bases his classification of the Echinoderms * falls to the ground.

But even granting Bury's observation to be correct, the fact would still remain that the tentacular system is entirely a product of the left water tube, and the *early stages* of the abactinal system are developed upon the right water tube before it has reached the anterior extremity of the Bipinnaria.† So that in either case the matter does not lie quite as simply as Semon imagines, when he tells us that in the passage from a Dipleurula stage to a Pentactula stage the axis of the Echinoderm is so twisted that the right side of the Dipleurula passes to the abactinal, and the left to the actinal side. Semon takes this twisting to be well explained by the assumption that the transition from the bilateral to the radial type was a fixed fact. This is carrying assumptions very far into the nebulous origin of things.

I fully agree with Ludwig as to the importance of regarding the plane in which the madreporic body is placed as of primary importance, and have called attention as far back as 1864 to its value in determining the axis of Echini and Starfishes.

Lovén, in 1871,‡ says: "Thus the asymmetry in the Echinoidean skeleton, with relation to its anterio-posterior axis (an artificial axis existing in Spatangoids and assumed for regular Echini) is expressed within each ambulacrum, in its two subordinate rows of plates, most strikingly in the arrangement, size, form, changes, and movements, during growth of the peristomial plates and those immediately following them, in the number and position of their pores, in the order of the appearance and disappearance of the sphæridia; and it will probably not fail, upon closer investigation, in the relations of the radioles and pedicellariæ."

That Lovén considered his anterio-posterior axis a feature acquired subsequently to the original axis for which I am claiming prominence as the primordial axis of the pluteus, is clearly shown in his own words, on page 39 of the Études sur les Échinoidées, where he says, " et l'on est

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* The types of the Crinoids, Ophiurans, and Starfishes he bases upon the well known structural features of the extension of the body cavity, of the genital organs, and of the diverticula from the digestive cavity into the tentacular region. He will find in the older writers (see L. Agassiz on the homologies of Radiates) very much the same characterization of the different types of Echinoderms which he attributes to Goette. Nor is the discovery of the difference in the development of the actinal and abactinal systems of Echinoderms due to Goette ; it was already observed in 1864.

† See Embryology of the Starfish, 1864.

‡ See translation of Lovén's article by Dallas in Ann. and Mag. of Nat. Hist., 1872, Vol. X. p. 429.

conduit à se demander s'il n'y a pas là un trait d'organisation, essentielle-
·ment propre à l'état intra-larval de l'Oursin, mais transféré à la forme
définitive que reçoit celui-ci en se développant dans son plateus, et s'il ne
serait pas possible que le diamètre *a ω* [the interambulacral space (*1*) be-
tween I, II, opposite to the ambulacral IV] désignât la position hété-
rologue qu'avait, par rapport à celui-ci, l'Échinoïdée naissant dans son
intérieur. S'il en est ainsi, le diamètre *a ω* serait son axe primordial, d'où
l'Échinoïdée aurait passé plus tard à une autre qui serait devenu l'axe
antério-postérieur de l'animal adulte."

I have always contended for this in my discussions on the position
of the axis of Echinoderms as determined by the madreporic body. From
the time I wrote the Embryology of the Starfish,* I have claimed that
the madreporic body denoted such a natural primordial organic axis, and
was placed in the suture of the two ends of the spiral upon which the
abactinal system of the young Echinoderm was developed, namely, upon
the right water tube. I have only claimed the prominent importance of the
axis denoting the suture of the ends of the spiral of the young Echinoderm,
and have most distinctly stated that in Spatangoids and other Echinoids,
where an apparent anterio-posterior axis is indicated by the presence of
the anus in the odd interambulacrum of the bivium opposite the central
odd ambulacrum of the trivium, the madreporic body was associated with
the right anterior ambulacrum. In so far I agree with the later views of
Lovén, — for our views are not so radically different as writers on Echino-
derms imagine, — as well as the earlier views of Desor and Cotteau. But I
have maintained that the regular Echini were still in a so called embryonic
stage, in which the anterio-posterior axis was not differentiated, and that,
while in the Spatangoids such an axis existed, the presence of the madre-
poric body in an interambulacrum did not denote that it was in the right
anterior interambulacrum, basing my objections not only on the structure
of the Desmosticha, but also on that of the Clypeastroids. For the reasons
more in detail I would refer to what I have said on the subject in various
papers on the Embryology and Classification of the Echinoderms, already
cited.

But as regards the primordial axis "*a ω*" which Lovén suggests may
be "essentiellement propre à l'état intra-larval de l'Oursin," and which,

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* See On the Young Stages of Echini, Bull. Mus. Comp. Zoöl., Vol. I. p. 279, 1869; Revision of
the Echini, pp. 639, 704, 1874; and Report on the Challenger Echinoidea, pp. 4–8, 1881.

according to him, is the axis passing from the interambulacrum 1 to the ambulacrum IV, this is not an axis which has any morphological value, or is characteristic of the pluteus stage of Echinoderms. Such an axis and the one which represents the suture of the spiral in the young Echinoderm is, on the contrary, an axis which corresponds to a line passing through the ambulacrum V and the interambulacrum 2. This will show fully as well as the tables which I gave in the Report on the Echinoidea of the Voyage of the Challenger (pp. 4–8) the artificial character of the axis he has called $a\omega$, passing through 1–IV, and to which he attributes so great a morphological value, — which is neither greater nor less than that of any similar axis passing through any of the interambulacra 3, 4, 5, to their opposite ambulacra I, II, III.

Therefore, if we wish to adopt a notation for the ambulacral and inter-ambulacral plates which is to have a morphological character, we must begin (in the Spatangoids) with the ambulacrum V [1], follow with the interambulacrum 4 [1]; ambulacrum IV [II], interambulacrum 3 [2]; ambulacrum III [III], interambulacrum 2 [3]; ambulacrum II [IV], interambulacrum 1 [4]; ambulacrum I [V], and interambulacrum 5 [5]. The new notation in brackets, [1] [3], being the notation which indicates the primordial axis in the young Echinoderm, while the other, beginning at V and going towards III, corresponding to Lovén's notation of V 2, is merely that of the artificial axis $a\omega$ of Lovén, which passes through from 1 to IV (Agassiz [4] [II]).

Sladen, it seems to me, has entirely misconceived Lovén's argument for the notation he has adopted, in defining as I, II, III, IV, V, the ambulacra of Echinoidea. He has drawn his arguments not from the fact that the madreporic pore indicates in the embryo the line of suture of the spiral abactinal system; but it is from the size of the ambulacral plates adjoining the actinal area that he has fixed his longitudinal axis. His anterior and posterior extremity is originally determined by the presence of a bivium and a trivium in Spatangoids, and then by analogy its homologue is fixed in the Eucchinoidea. I have, on the contrary, always insisted that the line of suture of the two ends of the spiral of the abactinal system was the only safe line to use as a guide for determining the axis of the Echini, since I first described the spiral condition of the Starfish embryo.*

* Embryology of the Starfish. p. 51.

# PLATE I.

1. Reconstructed arm of a broken specimen, No. 7, with part of the adjacent arm and the summit of their primary radials, $\frac{1.5}{1}$.
2. First branch, seen from above.
3. Second branch, seen from above.
4. Third branch, seen from above.
5. Parts of arm seen in profile between the first and second branches.
6. Part of arm seen in profile between the second and third branches.
7. Part of arm near middle of last branch, seen in profile.

# PLATE II.

$pn'$, first pinnule.                    $r$, first radial.
$pn''$, second pinnule.                 $z$, syzygy.

1. Specimen seen facing the right anterior interradium, $\frac{2}{1}$.
2. The same specimen seen facing the anal proboscis and azygous interradium, $\frac{2}{1}$.
3. Left anterior interradium of a broken specimen, $\frac{1}{1}$.
4. Anal proboscis and azygous interradium of the same, $\frac{4}{1}$
5. Junction of radials and interradials of azygous interradium of specimen No. 7, $\frac{4}{1}$.
6. The same of the right posterior interradium, $\frac{4}{1}$.
7. The same of the left anterior interradium, $\frac{4}{1}$.
8. The same of the left posterior interradium, $\frac{4}{1}$.
9. Junction of radials and interradials of left posterior interradium of broken specimen, $\frac{4}{1}$.
10. The same of right posterior interradium, $\frac{4}{1}$.
11. Junction of radials and interradials of left anterior interradium of another specimen, $\frac{4}{1}$.
12. The same of left posterior interradium, $\frac{4}{1}$.
13. The same, facing the azygous interradium, $\frac{4}{1}$.
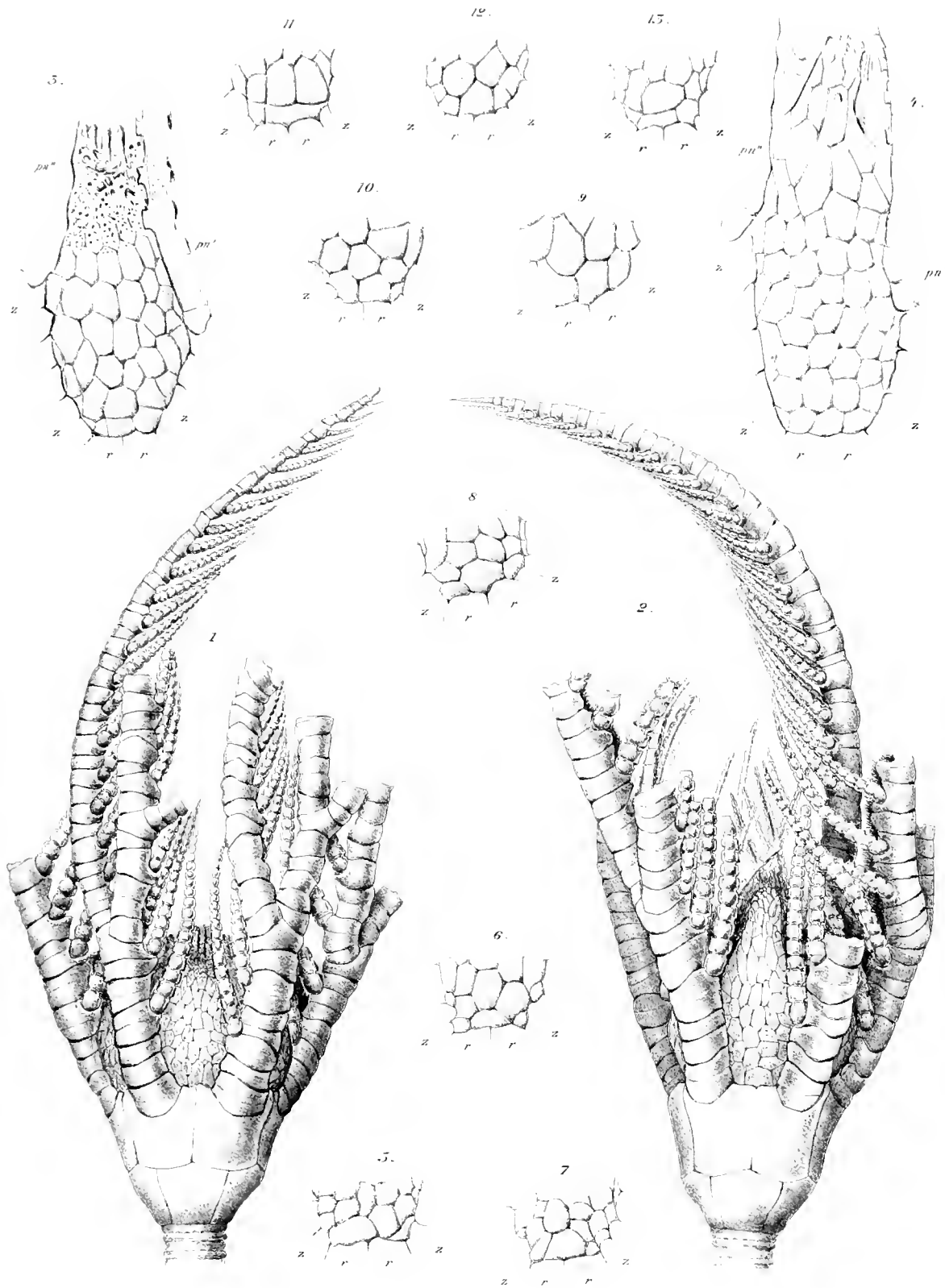
# PLATE III.

pn', first pinnule.                    r, first radial.
pn'', second pinnule               z. syzygy.

1. Specimen seen facing the anterior radium, $\frac{2}{1}$.   Same as Plate II. Fig. 1.
2. Another specimen seen facing the anterior radium, $\frac{3}{1}$.
3. Broken specimen seen facing the anal proboscis and the azygous interradium, $\frac{2}{1}$.

Figs. 4–10 from specimen shown in Plate III. Fig. 3.

4. Interradial plating between the first and second pinnules of adjacent arms.
5. First radial and lower part of arm to the second pinnule, seen in profile, showing the mode of attachment of the interradial plates to the arm joints.
6. Inner view of lower arm joints above first radial to the first pinnule, to show the mode of attachment of the interradial plating to the lower arm joints.
7. Profile view of interradial plating below the first pinnule of another arm from that of Fig. 6.
8. Interradial plating adjacent to the second pinnule, pn''; the arm joint is the upper brachial of Fig. 6.
9. Wing-like expansions of lower arm joints below second pinnule, adjoining the interradial plating, seen obliquely.
10. Interradial plating immediately above the first radial, seen obliquely.
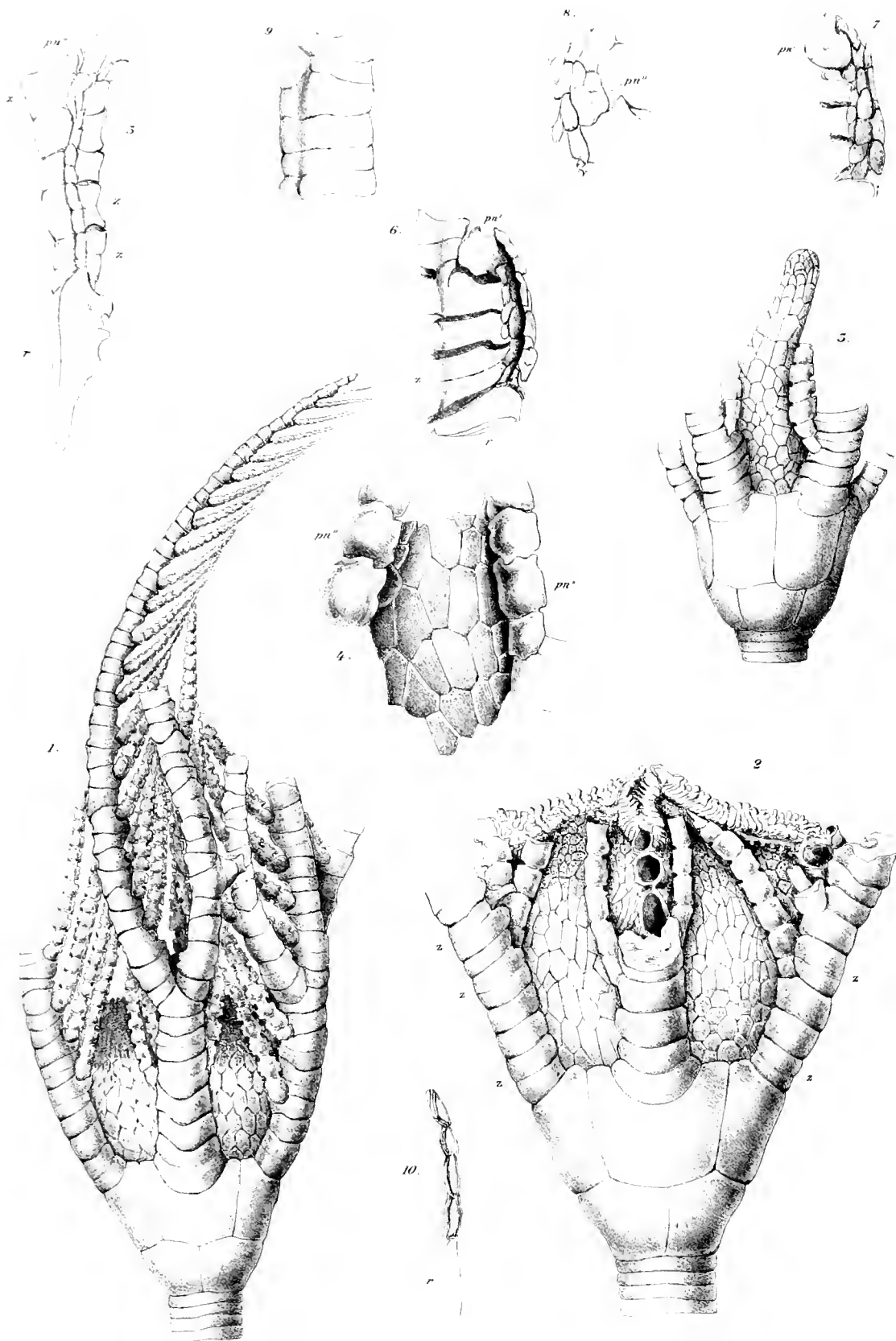
# PLATE IV.

ac, canal leading to arm.  
g, food groove.  
pn, pinnule.  
pn', first pinnule.

st, subtentacular canal.  
r, first radial.  
z, syzygy.

1. Arm of left anterior radial of a broken specimen, $\frac{2}{1}$.
2. Slightly oblique view of vault, showing the relation of the interradial plates of the vault and the plates covering the subtentacular canal and the food groove, $\frac{4}{1}$.
3. Interior view of upper part of perisomatic vault, showing food groove, the subtentacular canal, and the extension of the cœliac cavity as a groove into cavity of the arm, $\frac{2}{1}$.
4. The same as above, seen edgewise.
5. Interior view of upper part of interradial space, showing its connection with the edge of the arm joints and of the pinnules, $\frac{4}{1}$.
6. Interior view of lower interradial plates. $\frac{2}{1}$.
7. Base of the first pinnule, showing the connection of the lower interradial plates to the pinnule joints and to the smaller perisomatic plates, seen in profile.
8. Showing spongy character of the upper perforated perisomatic plates, magnified.
9. Exterior upper face of an imperforate interradial plate in the second row.
10. Lower interior face of the same.
11. One of the plates of the first row of interradials, exterior face.
12. Another plate from the first row of interradials, exterior face.
13. Plate of Fig. 11 seen edgewise to show its thickness.
14. One of the smaller imperforate interradial plates near the edge of fourth radial.
15, 16. Magnified views of reticulation of the interradial plates.

# PLATE V.

a,  anal opening.
ac,  canal of arm.
ap,  imperforate plates of anal interradium.
br,  first fork of arm.
g,  food groove.
g′,  ambulacral groove of pinnule.
cp,  covering plates.
o,  oral plates.
p,  perforated plates of interradium of disk.
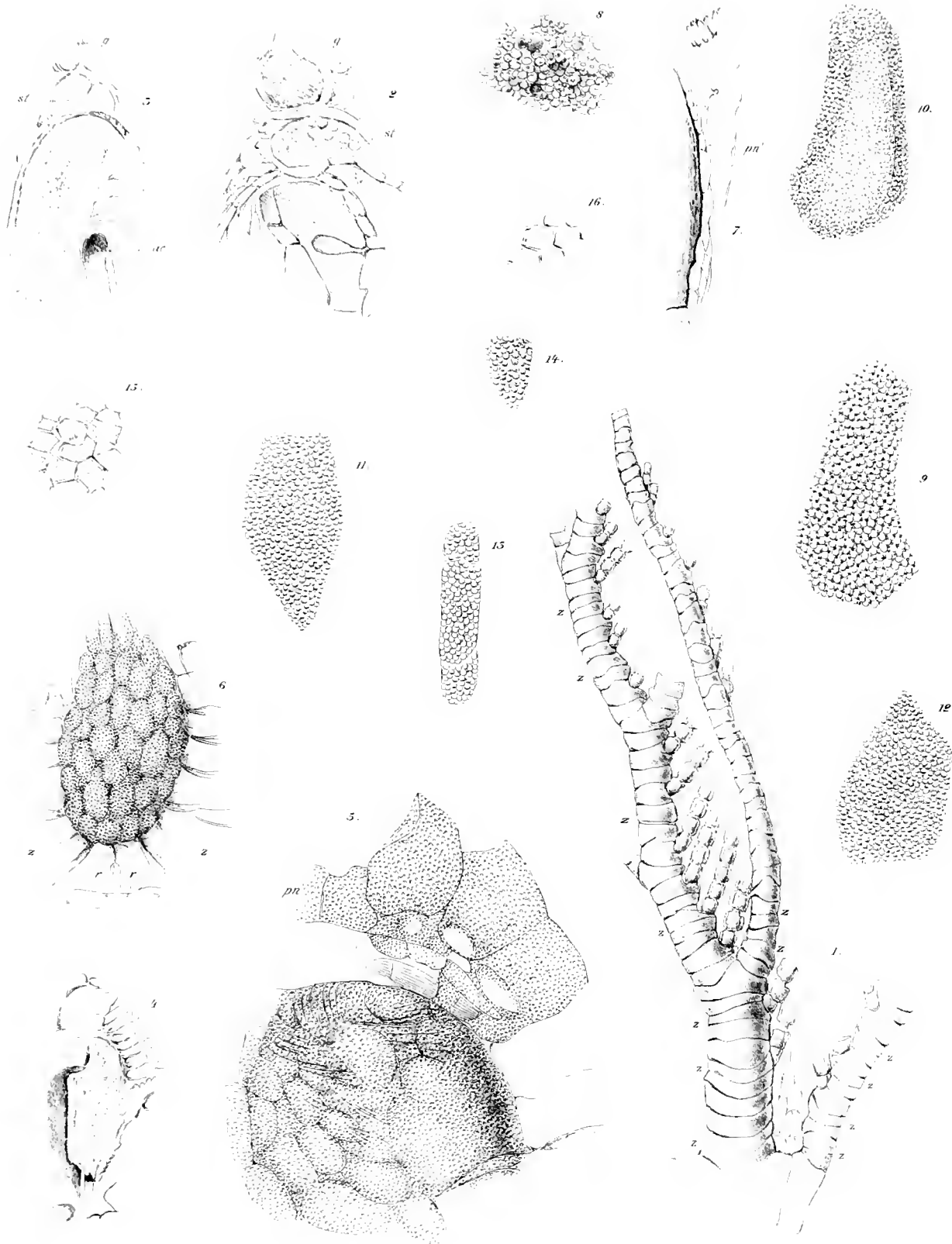
pl,  plates in continuation of disk, interradial plates extending along the base of the pinnules.
pn′,  first pinnule.
pn″,  second pinnule.
r,  first radial.
sp,  side plates.
st,  subtentacular canal.
t,  ambulacral tentacles.
z,  syzygy.

1. Right anterior interradial, showing the intimate connection of the interradial plates to the radials, and to the lower joints of the first pinnules, ⁴⁄₁. Specimen No. 8.

2. Anal interradium of same specimen, ⁴⁄₁.

3. Upper end of anal tube of specimen No. 7, seen obliquely from above.

4. Showing extension of imperforate interradial and perforated perisomatic plates to the main food groove, and along the side of the arm, as far as the first axillary, ⁴⁄₁.

5 Showing the further continuation of the interradial skeleton along the sides of the arm below the side plates (sp), beyond the first fork of the arm, ⁴⁄₁.

6 Showing side plates protecting the food furrow in middle of first arm. These side plates are not a part of the extension of perforated perisomatic plates.

7 Showing the extension of the plates of the disk along the base of one of the pinnules placed below the first fork of the arm.

8 Same pinnule seen facing the ambulacral food groove.

9. Tentacles of ambulacral furrow.

# PLATE VI.

1  Oral disk of specimen No 7 seen from above, showing limit of imperforated plates, ¼.

2. Mouth of specimen No. 1

3 Oblique view of food furrow extending from the mouth to the pinnules, to show the connection of the base of the pinnules with the disk; the left posterior groove adjoining anal interradium of specimen No 1.

4. Oblique view to show junction of perforated and impeforated interradial plates of disk, from specimen No. 8.

5. Seen facing the odd anterior arm, to show the vault formed by the perforated and imperforated interradial plating on each side of the arm, supporting the arm canal (*ac*), the subtentacular canal, and the food groove (*g*).   Specimen No. 7.

Figs. 6–10 from specimen No. 1.

6. Oblique view of arm showing the continuity of the plating of the vault flanking the arm canal, the subtentacular canal, and the food groove.

7. Interior view of part of food groove adjoining the oral plates, together with the contiguous subtentacular canal, arm canal, and the lower part of the interradial plating of the adjacent arm.

8. Interior view of the upper part of the vault, showing arm canal, pinnule canals, and the plating of imperforated plates ; the left pinnule canal should be lettered *pc*.

9. Interior view of the upper part of the vault, and the adjacent subtentacular canal and food groove, facing the angle of the oral plates.

10. Irregular plates forming the bottom of the food furrow seen from the interior of the disk.
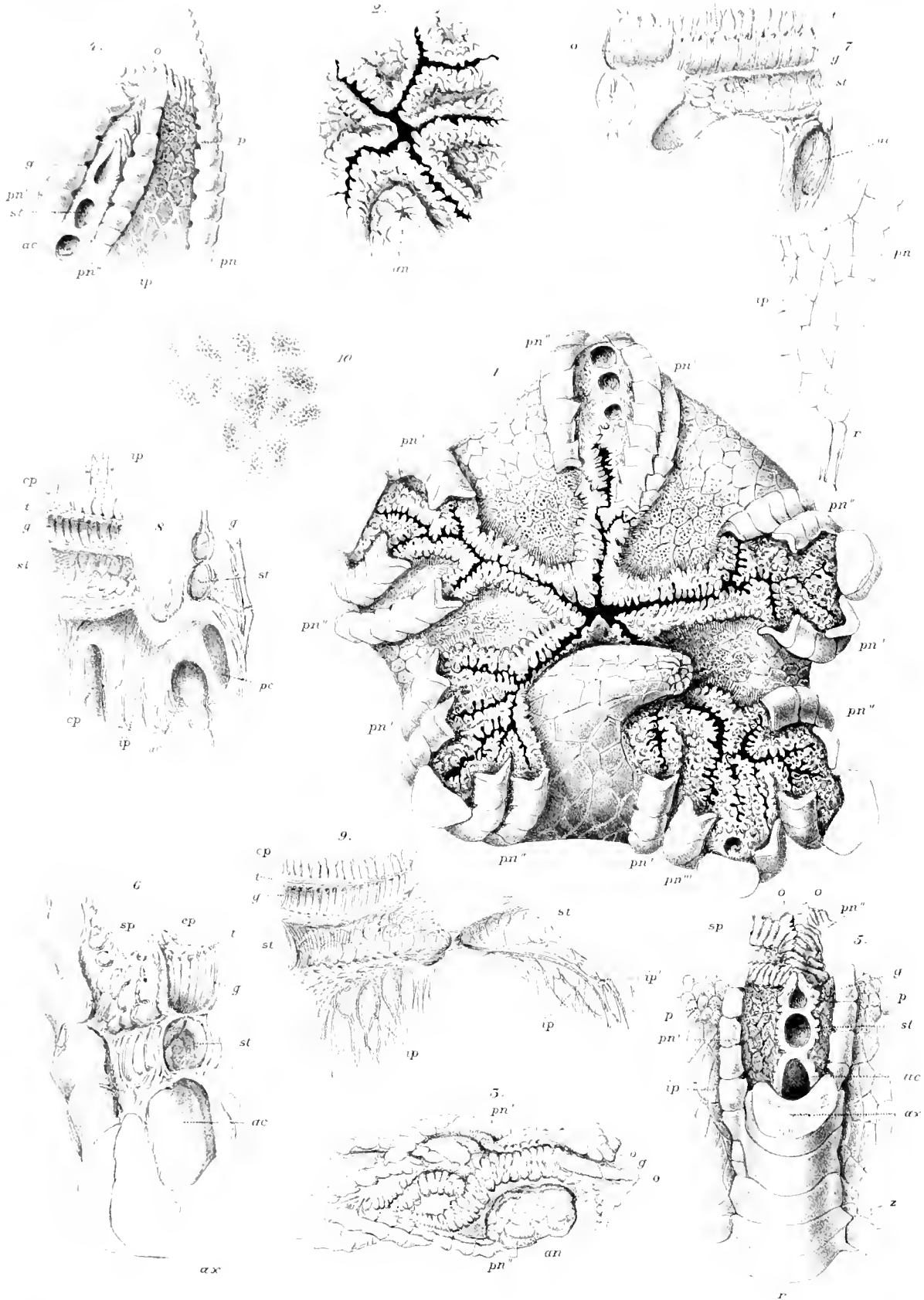
# PLATE VII.

*cp*, covering plates.        *g*, food groove.        *sp*, side plates.

1. Showing food groove with its covering and side plates, from the base of an arm near its junction with the disk.
2. Same as Fig. 1, from near the base of another arm.
3. Profile view of side plates of the food groove of the disk, between the second and third forks.
4. Side plates and covering plates of the food groove of one of the arms between the second and third forks, from above.
5. The same as Fig. 4, seen in profile, but above the third fork of the arm
6. Profile of side plates and covering plates of an arm between the second and third forks.
7. Same between the third and fourth forks.
8. Covering and side plates seen from above between the first and second forks.
9. Covering and side plates of the food groove about the middle of the arm.
10. Profile of covering and side plates towards the end of the arm.
11. Same plates as Fig. 10, still farther out towards the extremity of the arm.
12. One of the covering plates of arm near those of Fig. 11, to show its connection with the supporting side plates.
13. Side plates of food groove of arm above the second fork, seen in profile.
14. View from above of covering plates and side plates between the third and fourth forks.
15. View from above of covering and side plates nearer the extremity of the arm than those of Fig. 11.
16. Profile of plates still nearer the end of the arm.
17. Food groove from above, at the second fork
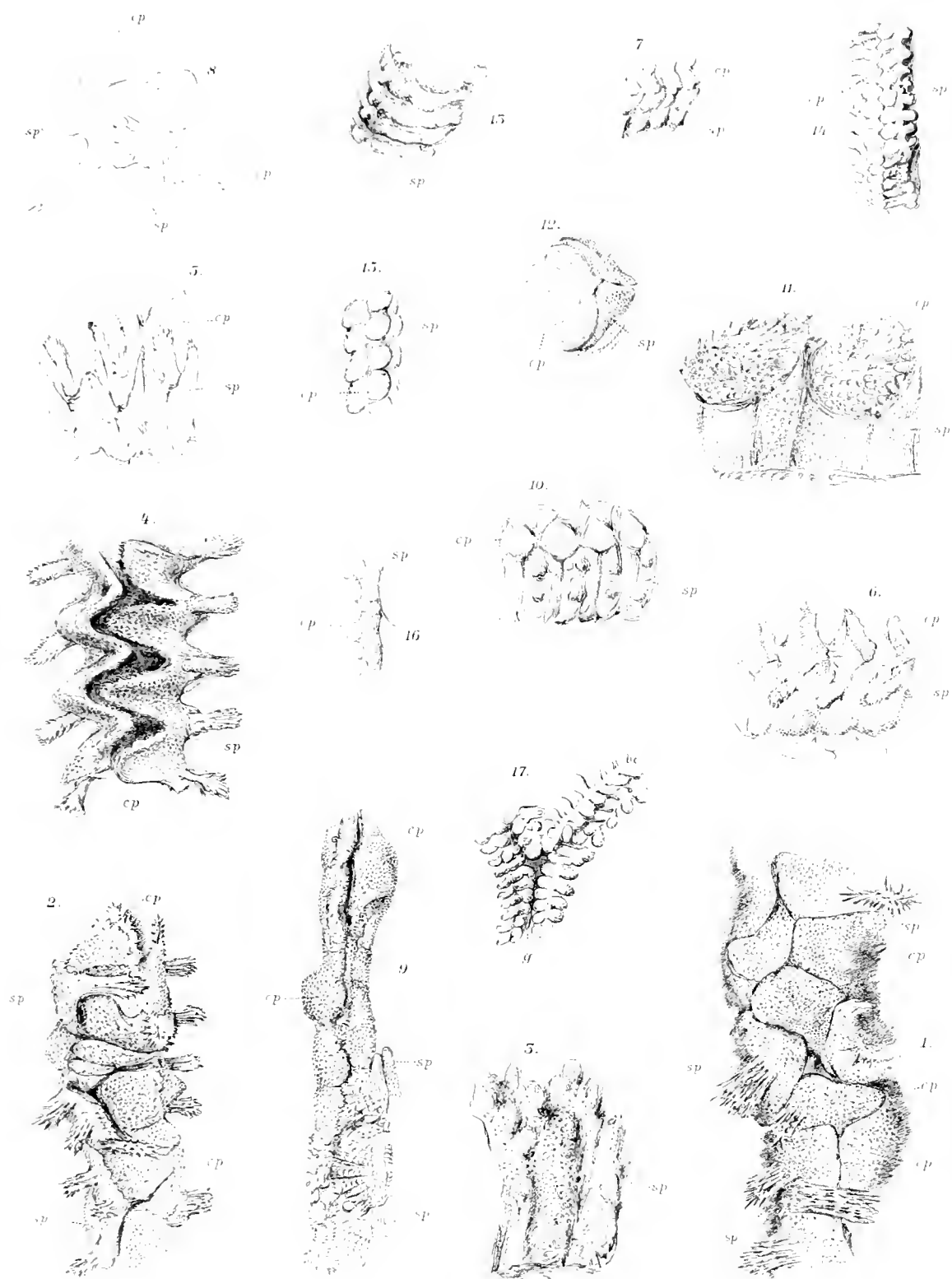
# PLATE VIII.

1. Profile view of side plates and covering plates near middle of arm.
2. View from above of covering plates nearer base of arm than Fig. 1.
3. View from above of covering plates from the arm beyond the last fork.
4. View from above of covering plates from the arm on the proximal side of the last fork, showing opening for the passage of the tentacle.
5. Slightly oblique view of two of the covering plates from nearly the same part of the arm as Fig. 4, to show the opening for the passage of the tentacle.
6. Profile view of covering and side plates and tentacles near the third fork of the arm.
7. A part of the arm furrow seen from above, to show the arrangement of the tentacles.
8. Side view of the basal part of one of the pinnules near the disk, to show the covering and side plates.
9. A part of the same pinnule as Fig. 8, seen from above.
10. Profile of side and covering plates of a pinnule near the end of the arm proximal to last fork.
11. Ambulacral groove of arm between the second and third forks.

7.

6.

9.

sp

cp

cp

rp

cp

sp

t

t

t

11.

8.

2.

10.

sp

sp

cp

sp

sp

sp

cp

cp

cp

sp

cp

sp

sp

cp

sp

5.

sp

cp

cp

t

f

4.

1.

cp.

sp

3.

cp

cp

sp

cp

cp

cp

sp

cp

sp

# PLATE IX.

*a*, *b*, *c*, *d*, *e*, *f*, first, second, third. fourth, fifth, and sixth side plates adjoining the oral plate *o*.
*g*, food groove.
*o*, oral plate.
*o'*, keel of oral plate.
*p*, pores of perforated interradial plates adjoining food groove on the central part of the disk.

1  Calcareous plates adjoining the food groove about one third the distance from the oral plates to the branch leading to the first pinnule.

2  Perforated plates on the interradial part of the disk adjoining the line of imperforated plates.

3. Magnified view of the calcareous network forming the pores, *p*, of the perforated interradial plates of the disk of Fig. 2.

4. Reticulation surrounding one of the pores. *p*, of Fig. 2.

5. Spongy reticulation surrounding the pores upon the proximal perforated plates.

6. Optical section of the reticulation of one of the perforated plates, to show the irregular course of the canals formed by the pores. *p*.

7. Slightly oblique profile of one of the oral plates and the adjoining side plates.

8. The plates *o*, *a*, *b*, and *c* of Fig. 7 isolated, seen in profile.

9. Another oral plate seen in profile from the right.

10. The same oral plate seen facing the keel. *o'*.

11. The other profile of the oral plate (see Fig. 9).

12. Plate corresponding to plate *a* of Fig. 8 on the face of the adjoining food groove.

13. The plate corresponding to *b* of Fig. 8.

14. The plate corresponding to *c* of Fig. 8.
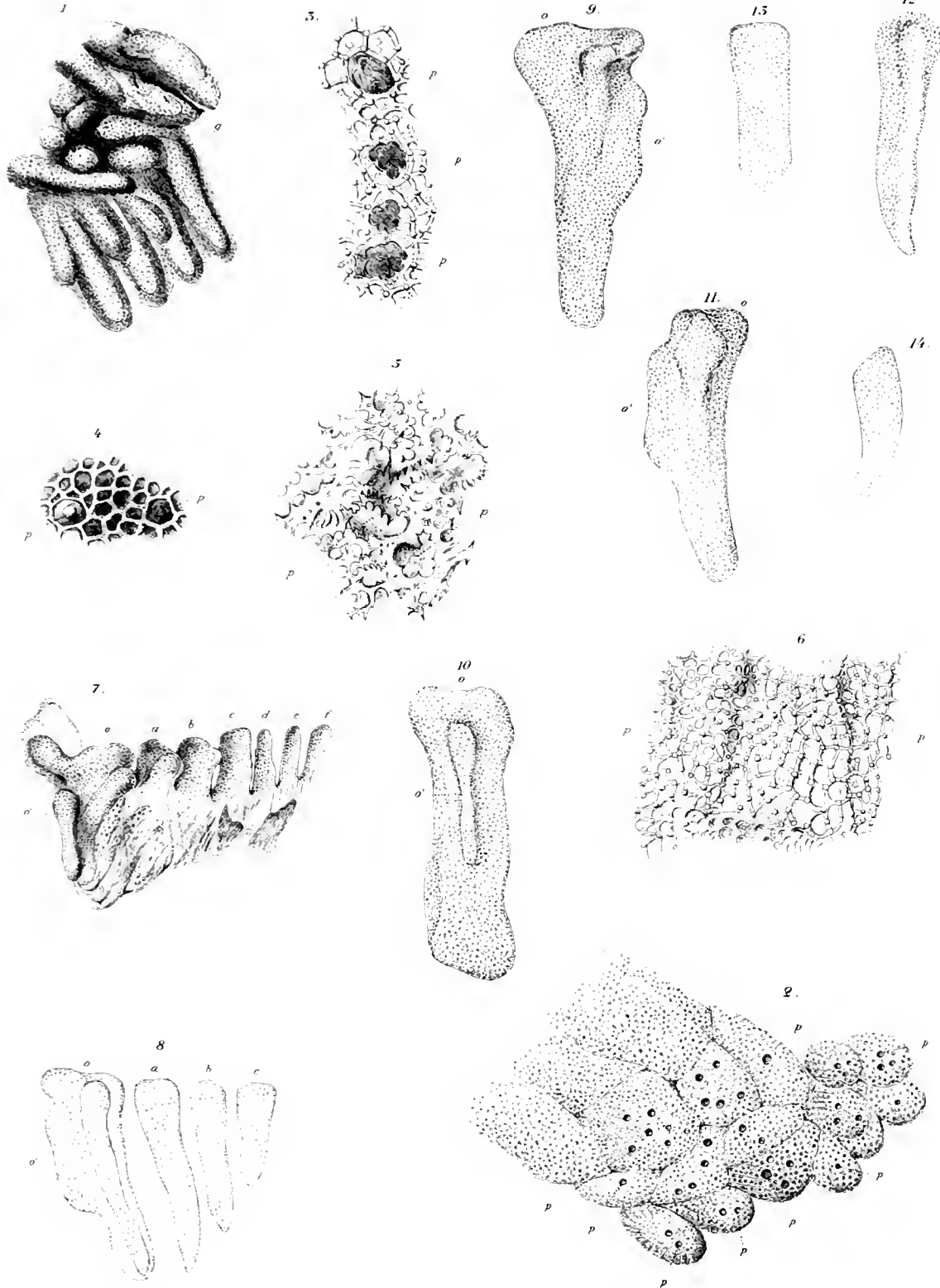
# PLATE X.

Figs. 1–7 are some of the calcareous plates and spines from the plates adjoining the food groove of Plate IX. Fig. 1, after boiling with potash.

8. Magnified view of the reticulation of some of these calcareous plates (of Fig. 1).

9. Saddle-like base of the covering plate of a basal pinnule which rides upon the side plates.

10. The point of one of the covering plates similar to that of which the base is given at Fig. 9.

11. Spiny and fan-like projections of the base of another covering plate of a basal pinnule.

12. Magnified view of the reticulation rising from the general surface at the base of the wings of the covering plate of Figs. 9 and 11.
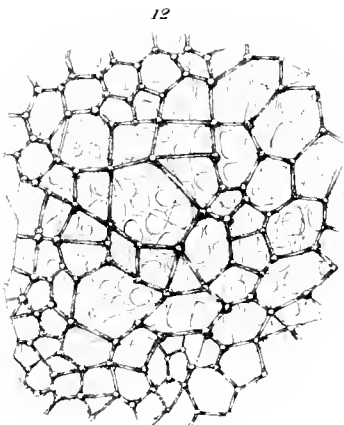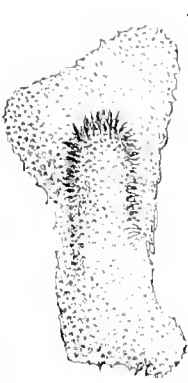
# PLATE XI.

1. Calcareous network of limestone of a side plate of food groove near middle of arm.
2. Large covering plate with terminal reticulation grown into spines.
3. Covering plate of food groove of pinnule, with large open meshwork extremity.
4. A smaller covering plate of the same groove as Fig. 2, also terminating in spines.
5. Thickening of reticulation to form a lateral spine.
6. One of the spines of the side plates.
7. Another of the spines of the side plates.
8, 9. Small covering plates of end of arm joint near extremity of arm.
10. Calcareous limestone network of side plate of food groove of pinnule, about middle of arm.
11 Covering plate of same pinnule nearer base of same, seen from above.
12. A similar covering plate to that of Fig. 11, seen from the interior face.
13. Profile view of covering plate, showing the wings connecting them with the side plates (Fig. 10). See spines of Fig. 9, Plate X.
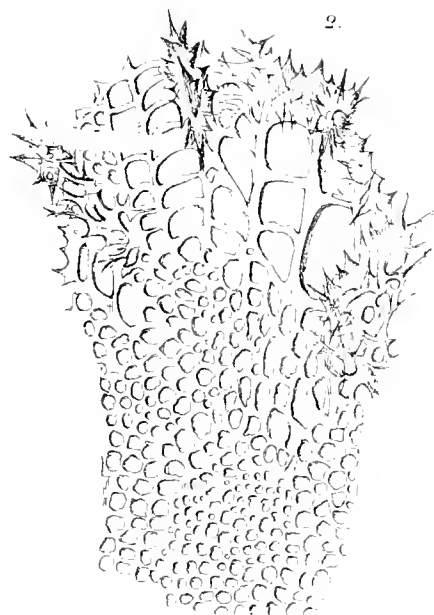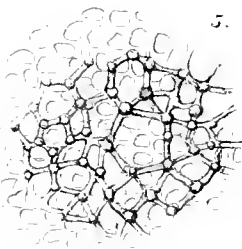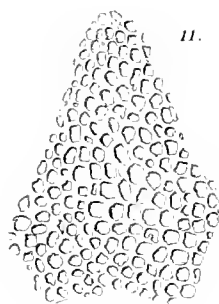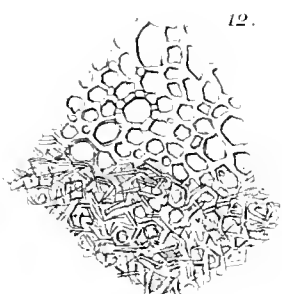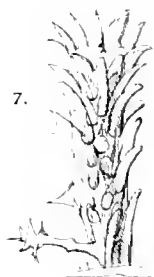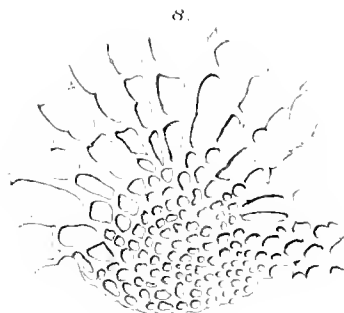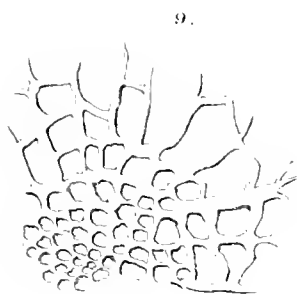
# PLATE XII.

1. Calcareous reticulation of side plate of food furrow of middle of arm.
2. Another side plate from the same region.
3, 4, 5. Different types of side plates of the same groove.
6. Side plate from groove near end of arm.
7. Covering plate of end of arm.
8. Oblique view of fifth joint from end of arm.
9. Profile of a young arm joint near end of another arm (similar to **Fig.** 8).
10. Calcareous floor separating the axial canal of the arm from the food groove of a joint about in the stage of Fig. 9.
11. A young arm joint, the penultimate.
12. End view of same, showing axial canal.
13. Terminal arm joint.
14. Extremity of arm.
15, 16. Articulations of young terminal arm joints.
17. Syzygy of young arm joint.
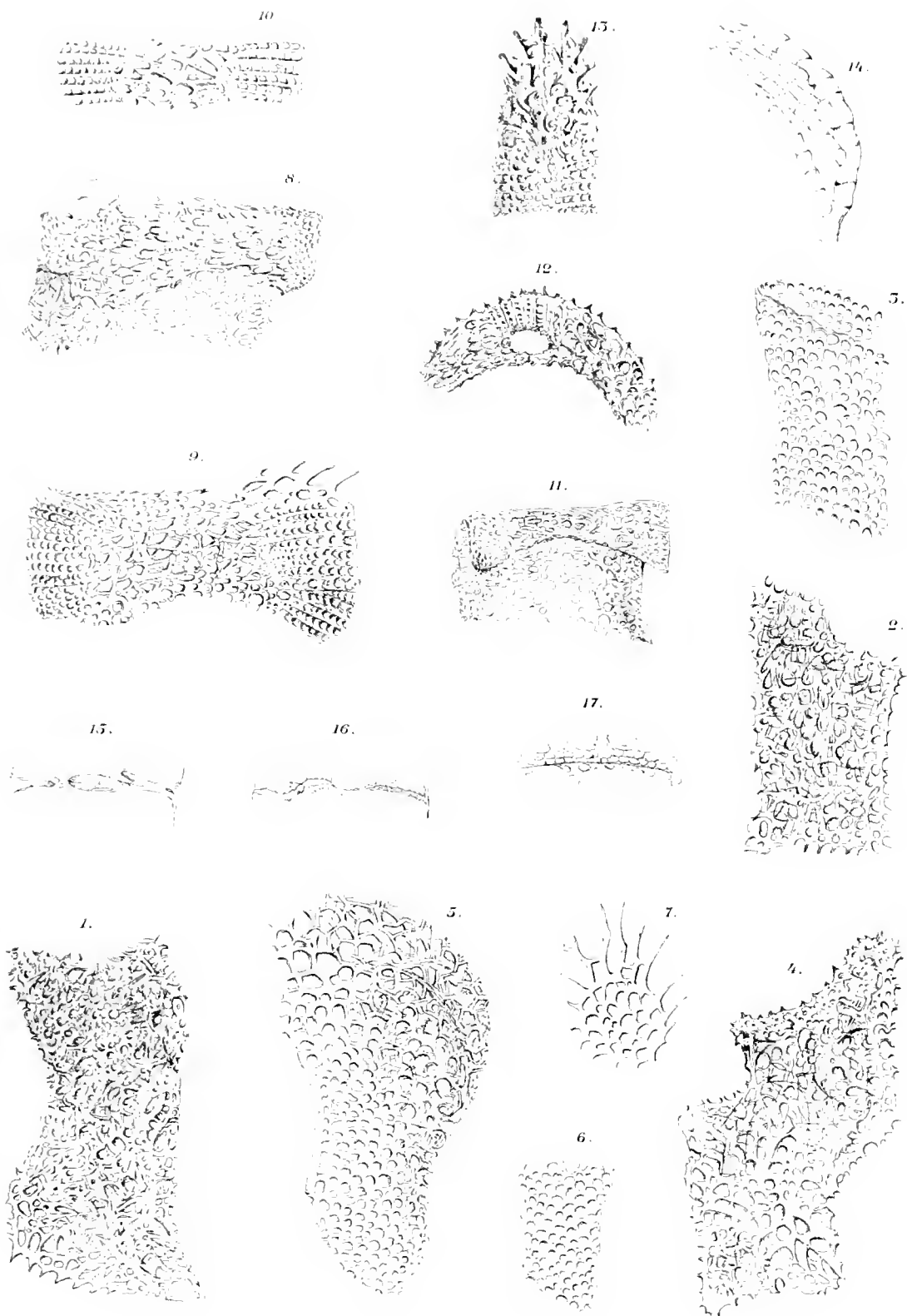
# PLATE XIII.

*pi*, point of attachment of pinnule.

1. Distal view of pinnule joint near base of pinnule near calyx.
2. Oblique end view showing axial canal of pinnule joint near extremity of an arm.
3. Profile view of young arm joint.
4. Another joint, still nearer the end of the arm.
5. Oblique view of a joint nearer the extremity of the arm than Fig. 3.
6. Same joint seen from inside to show the floor of the axial canal.
7. Smaller joint, the third from the end of the arm.
8. Penultimate joint of the arm.
9. End view of a joint like that of Fig. 4.
10. End view of a joint similar to Fig. 3.
11. Proximal face of hypozygial, above the third fork.
12. Syzygy face of hypozygial.
13. Proximal face of another joint, from same part of arm
14. Distal face of same joint; *pi*, insertion of pinnule.
15. Epizygial and hypozygial from the middle part of the arm above the third fork; *pi*, insertion of pinnule.
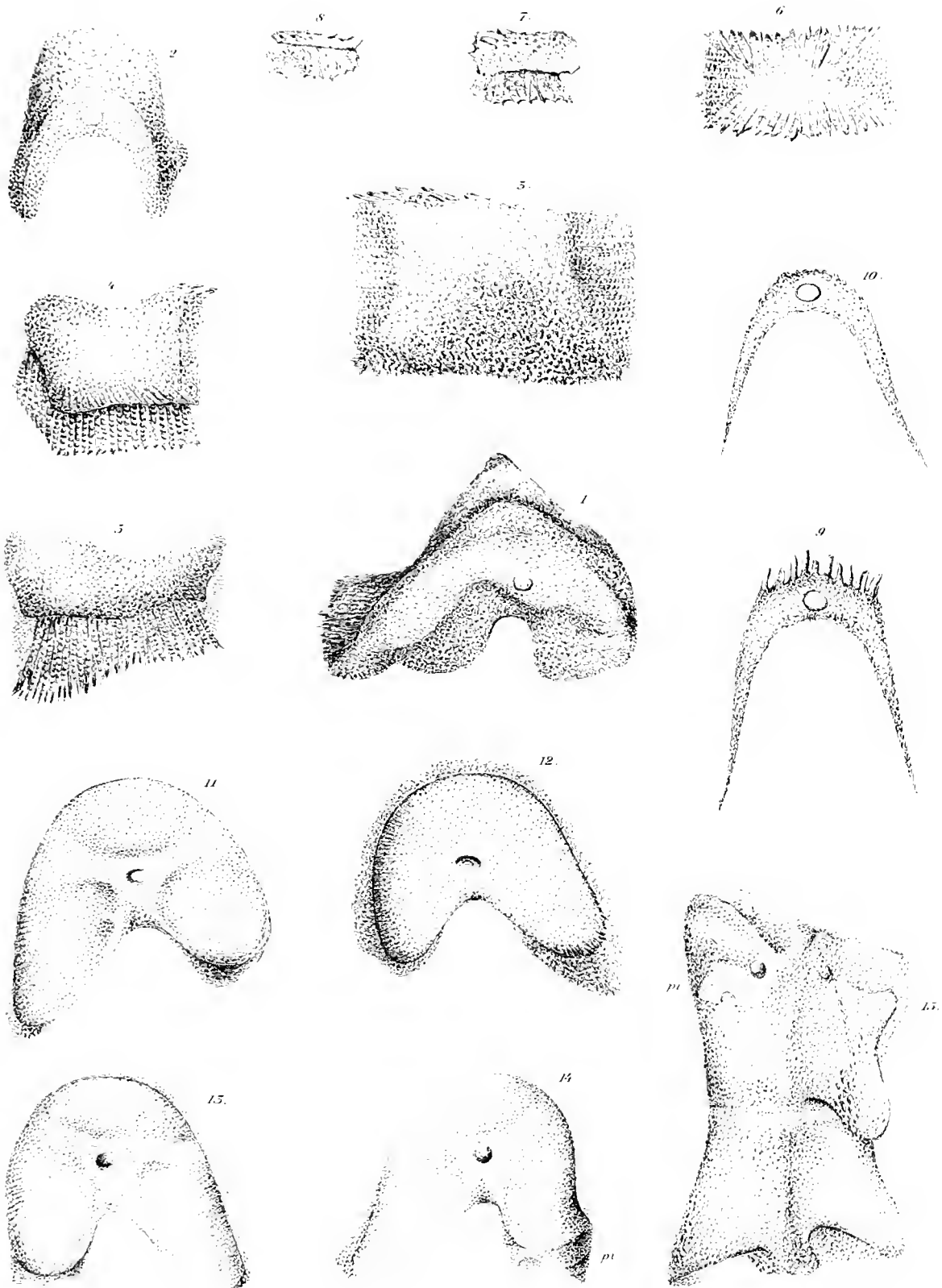
# PLATE XIV.

*pn*, point of attachment of pinnule.

1. View from below of arm joint near the middle of the arm above the third fork, showing insertion of pinnule.
2. Proximal face of same.
3. Distal face of same.
4. Proximal face of hypozygial of same part of arm.
5. Syzygy face of same joint.
6. Lateral view of joint from first fork of arm, seen facing canal of pinnule.
7. Oblique view of same, showing pit of pinnule.
8. Distal face of same joint.
9. Proximal face of arm joint from first fork of arm.
10. Joint below axillary of second fork, distal face.
11. Axillary of second fork, seen from above.
12. Distal face of same joint, showing the two openings of the axial canal leading into the forks.

# PLATE XV.

2.

1.

5.

3.

4.

10.

7.

12.

11.

8.

9.

6.

*pn*

*pn*

*b*

*c*

*a*
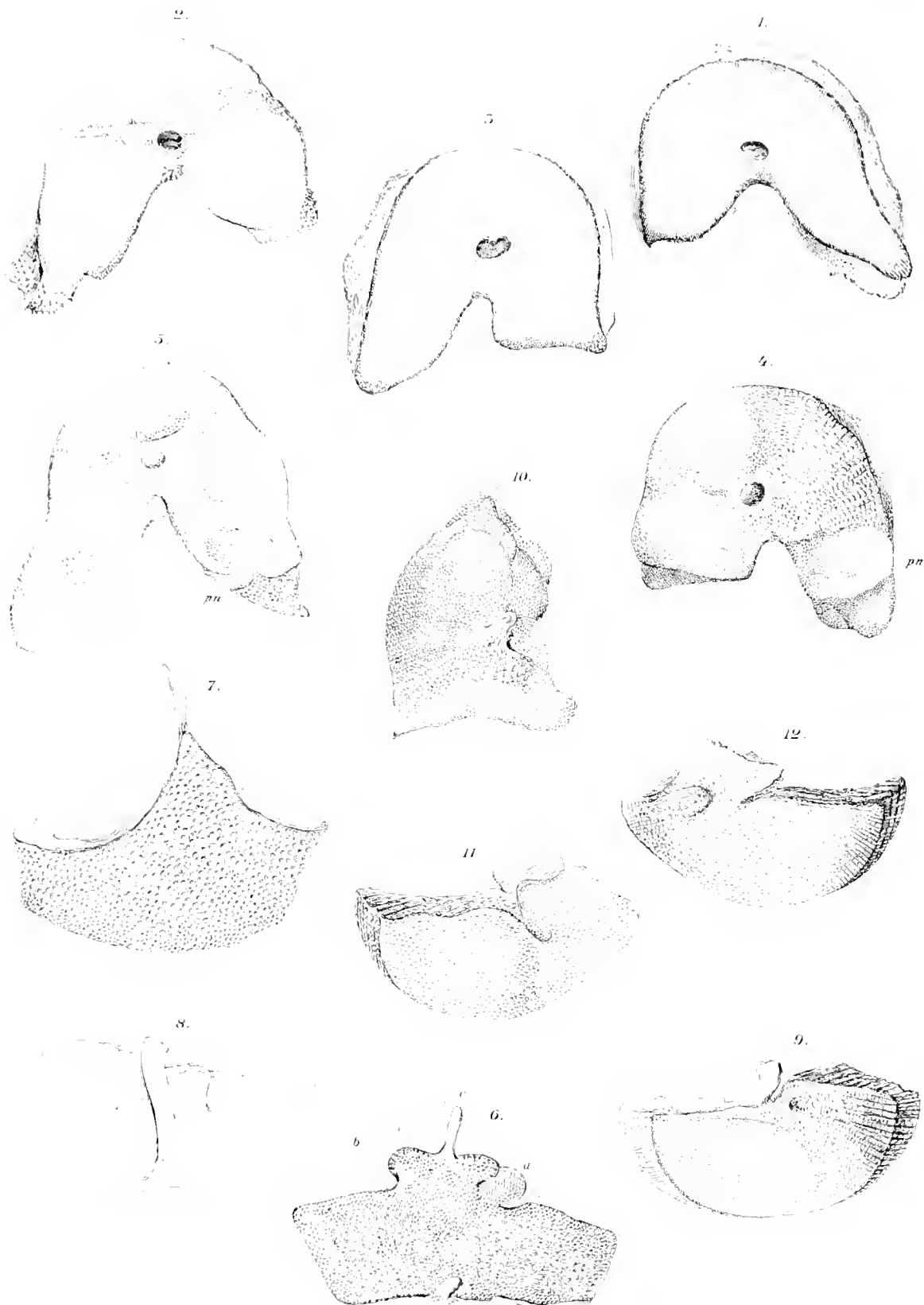
# PLATE XVI.

1. Pinnule of base of arm.
2. Pinnule of part of arm above first fork.
3. Pinnule of the first third of second fork.
4. Pinnule near end of main arm.
5. Pinnule at base of last fork.
6. One of the lower joints of a pinnule near the calyx, seen from above.
7. End view of same.
8. Oblique view of a similar joint, seen from the interior.
9. Another joint near the middle of the same pinnule, seen from above.
10. A joint of same pinnule nearer the end, with one wing but slightly developed, from above.
11. Inside view of a joint with only one wing.
12 A similar joint, seen from the inside.
13. Joint without wings, near the extremity of the pinnule.
14. Reticulation of wing of a pinnule joint.
15. Reticulation of central part of joint, dorsal aspect.
16. Reticulation of interior of joint, the anterior edge and part of the floor of the axial canal.
17. Reticulation of edge of joint of pinnule.
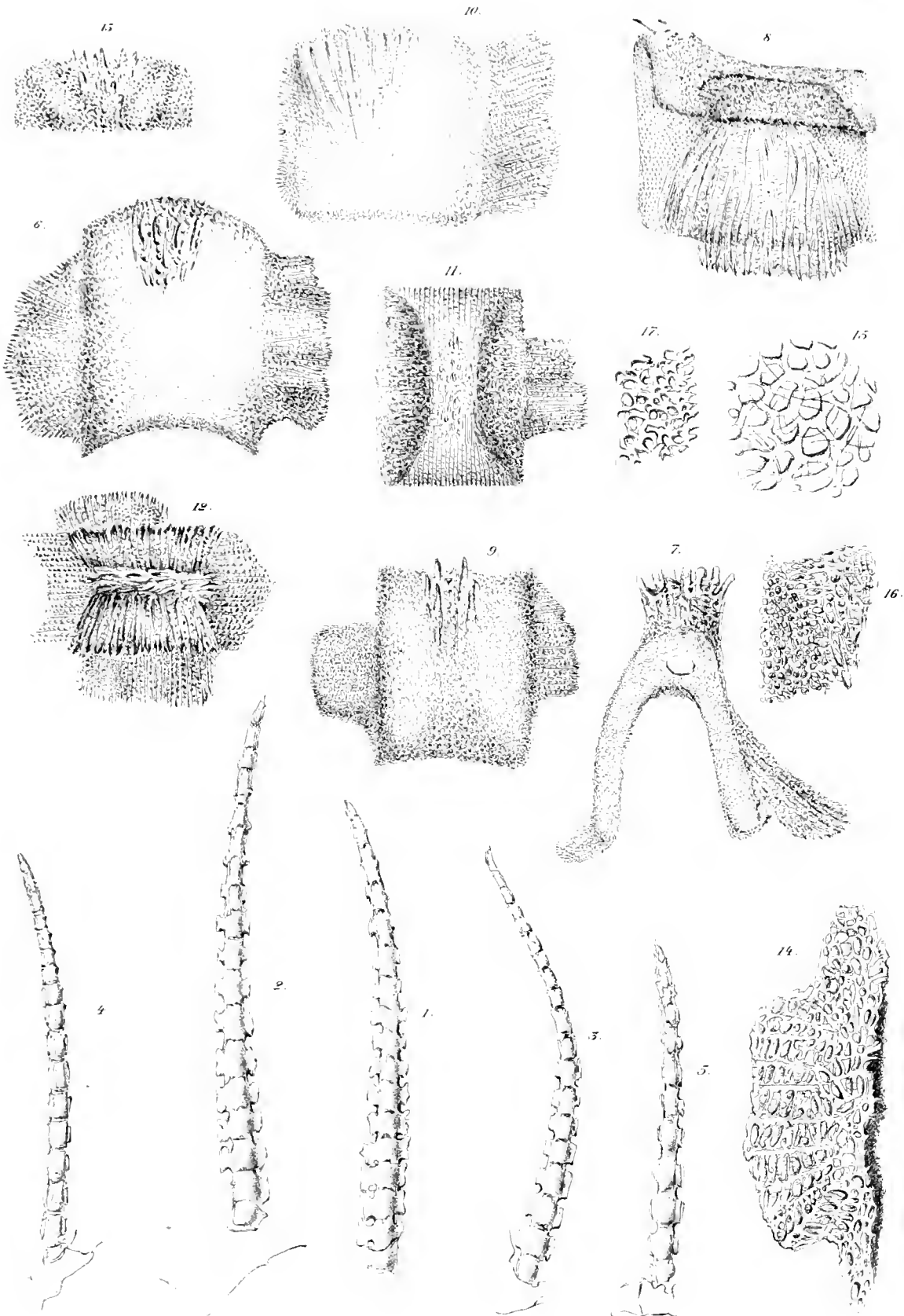
# PLATE XVII.

1. Joints of the stem of specimen (No. 8) adjoining the calyx, with alternating ribbed and flat joints, and serrated sutures ($\frac{4}{1}$).

2. Curved part of the stem of specimen (No. 8) immediately below the joints shown in Fig. 1 (eight rings, more or less crushed, to be intercalated between Figs. 1 and 2).

3. Part of one of the crushed rings showing edge of rib of one joint, a flat joint with the wedges of a new joint both above and below it ($\frac{8}{1}$).

4. The joints of the upper part of Fig. 2, at point marked $a$ ($\frac{4}{1}$).

5. The joints of the same stem at point marked $b$.

6. The joints of the same stem at point marked $c$.

7. The joints of the same stem at point marked $d$.

8. The curved upper portion of the stem of specimen No. 1, showing the passage of the smooth rings into ribbed and flat joints, more and more serrated in proportion to their distance from the calyx ($\frac{2}{1}$).

9. Joints of the stem of specimen No. 1 adjoining the calyx, with smooth or slightly serrated sutures and isolated granules gradually passing into coarse tubercles connected by horizontal ridges ($\frac{4}{1}$)

10. The opposite side of the stem of Fig. 9.

11. A few rings of the middle part of the stem of Fig. 8 at $a$, to show the prominent transverse ridges and the flat rings, both with finely serrated sutures ($\frac{4}{1}$).

12, 13. Parts of a stem (of another specimen?) slightly curved, in which the ribs have passed into a mere angular outline of the joint ($\frac{2}{1}$). Figs. 12 and 13 are contiguous parts of the same stem.

14. Magnified joints of stem of Fig. 12 at point marked $a$ ($\frac{4}{1}$).
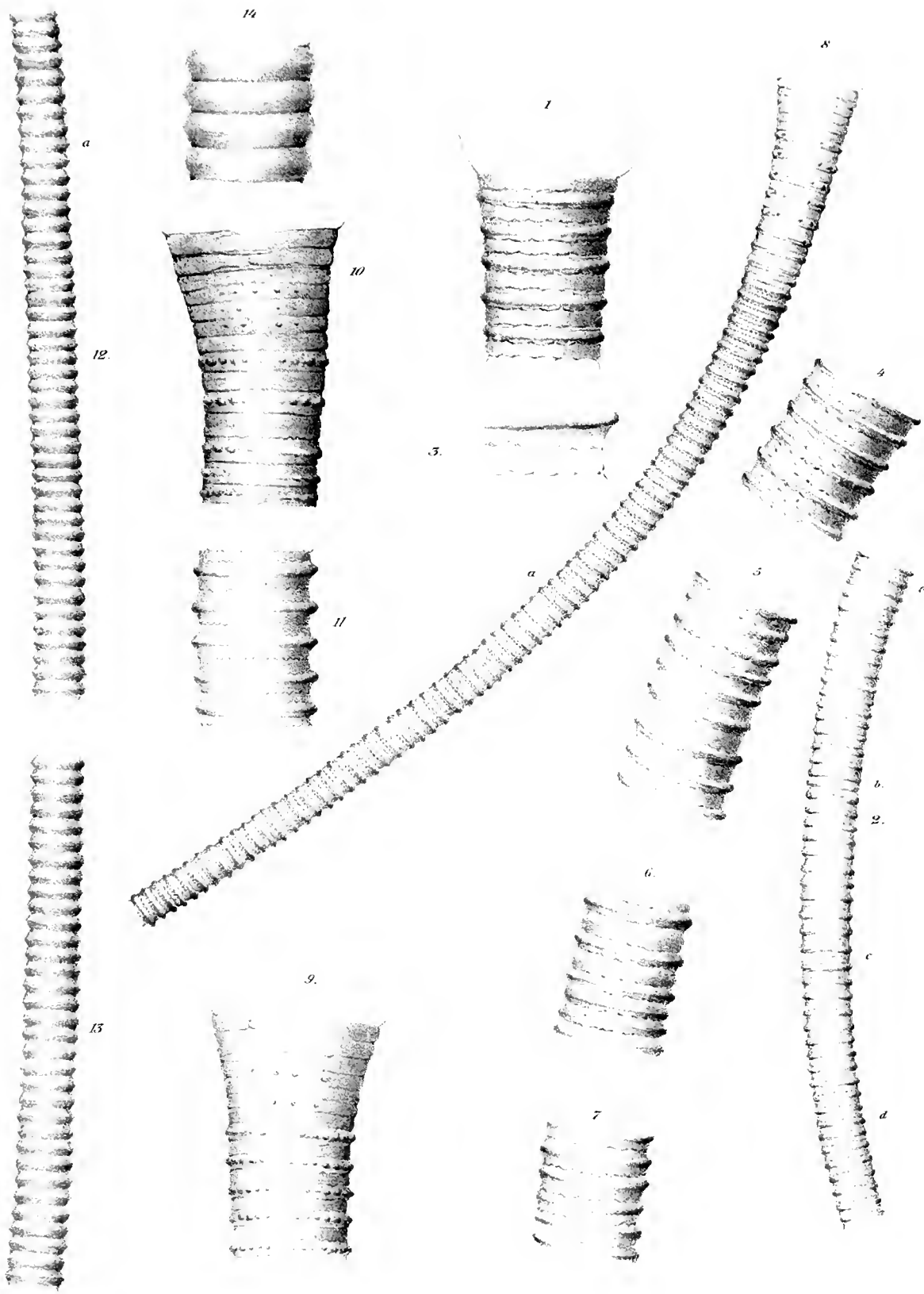
## PLATE XVIII.

1. Basal part of calyx, with upper joints of stem of specimen No. 7 ($\frac{4}{1}$).

2. Curved part of the stem immediately below the joints figured above Fig. 1, eight to nine joints more or less crushed ($\frac{2}{1}$).

3, 4, 5, 6. Joints of parts of stem of Fig. 2, at points marked $a$, $b$, $c$, $d$ ($\frac{2}{1}$).

3$^a$. Some of the joints of Fig. 3, showing the angular character of the joints ($\frac{4}{1}$).

4$^b$. Some of the joints of Fig. 4, after they have passed to flat rings, with only an occasional indistinctly ribbed joint ($\frac{4}{1}$)

5$^c$. Some of the joints of Fig. 5 with closely serrated sutures, and scarcely ribbed, before passing into stage of Fig. 6$^d$ ($\frac{4}{1}$).

6$^d$. Some of the joints of the lower end of the stem of Fig. 6, of a slightly less diameter than those at the upper end, with smooth sutures and convex sides ($\frac{4}{1}$).

7, 8. Probably contiguous parts of the stem of specimen No. 7 intermediate between that of Fig. 2 and that of Fig. 9, with joints of nearly uniform height, having convex sides and smooth sutures ($\frac{2}{1}$).

7$^a$. A few joints of Fig. 7 at the point marked $a$ ($\frac{4}{1}$).

9. A part of the stem, probably of specimen No. 7, following nearly the joints of the stem of Fig. 8 ($\frac{2}{1}$). This part of the stem widens very perceptibly towards the lower part, and, judging from the basal parts of the stems of several fossil species of Apiocrinus, must have been near the root.

9$^a$. Magnified joints of lower part of stem of Fig. 9, at point marked $a$, with smooth sutures and convex sides.

# PLATE XIX.

Pl. 15.

# PLATE XX.

1. Dorsal view of the calyx.
2. Interior view of radials from the first radial to the joint above the base of the second pinnule.
3. Distal face of the first radial.
4. Side view of the first radial.
5. Proximal face of the first radial.
6. Proximal face of the second radial.
7. Distal face of the second radial (third articulation, including the syzygy).
8. Distal face of the third radial.
9. Muscular bundles of the first radial, extending across from the wedge-shaped projections, *rw*, *rw′*.
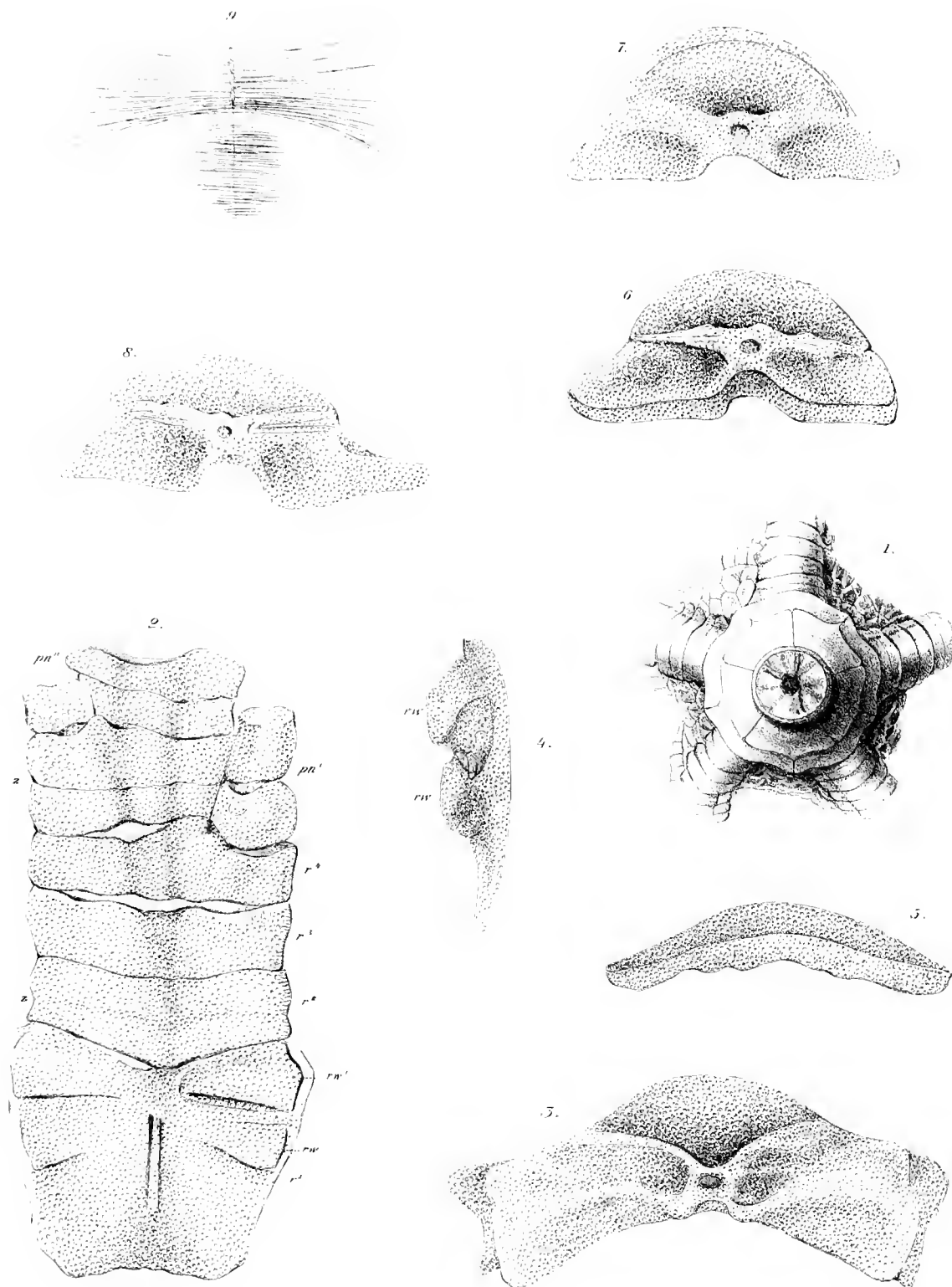
# PLATE XXI.

1. Distal convex face of the "article basal," the top joint.
2. Proximal face of same.
3. Young joint or anchylosed infrabasals? resting upon the convex face of the "article basal" (Fig. 1, on the central part).
4. Reticulation of central part of proximal surface of basal joint.
5. One segment of a young stem joint with sixteen lobes, lying between the eighth and ninth joints.
6. Sixth stem joint, distal face, with fourteen irregular primary ridges and numerous minor peripheric ones.
7. The proximal face of the same, having sixteen primary sockets.
8, 9. The distal and proximal faces of the ninth joint, with sixteen primary ridges bifurcating near the edge and their corresponding sockets on the opposite face.
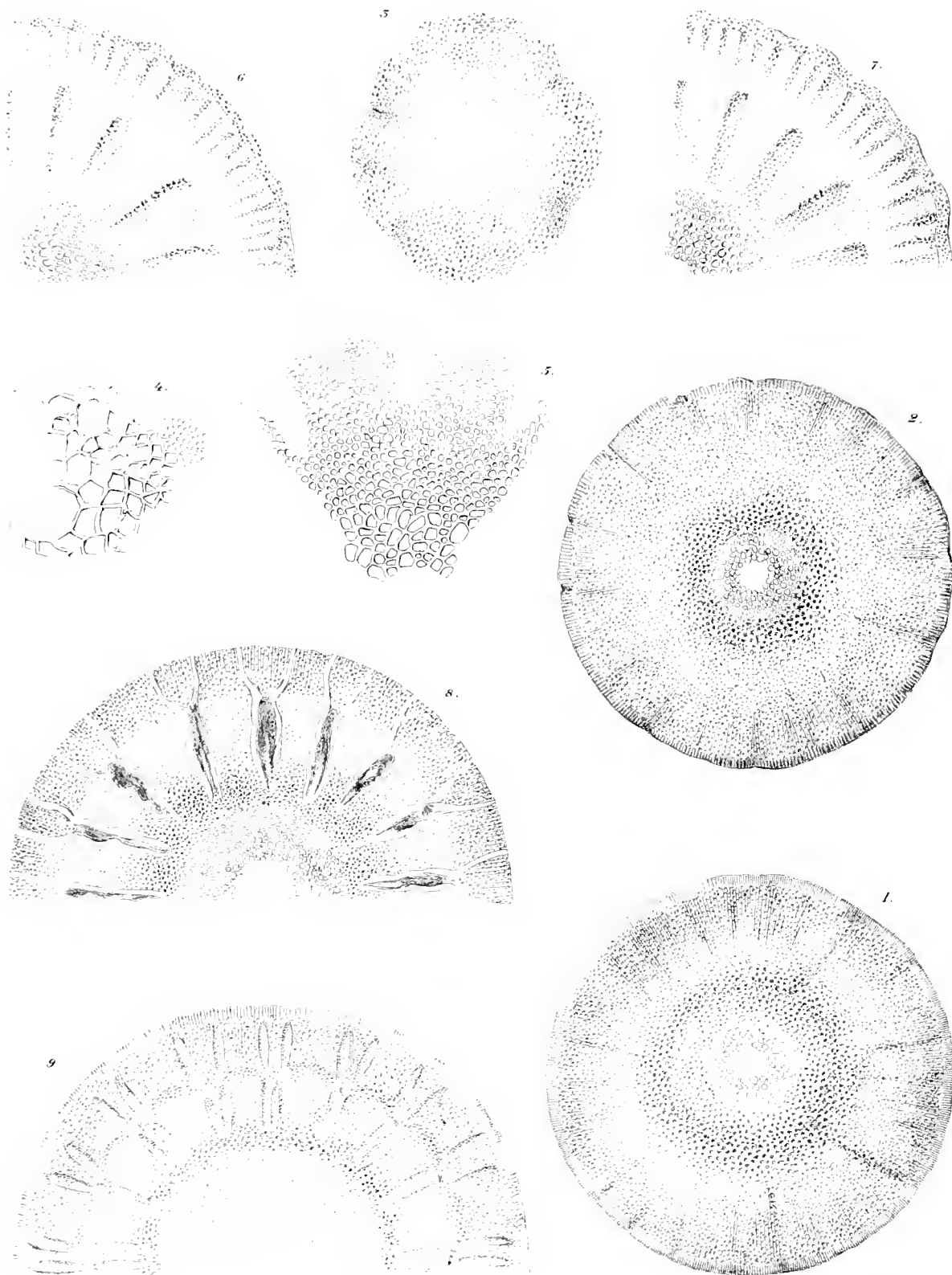
## PLATE XXII.

1. A piece of the upper part of the stem of Plate XVIII. Fig. 3.
2. Three rings of the same, more magnified, showing the extremities of the wedge-shaped lobes of the young joints forcing their way between the flat and the ribbed joints.
3. Proximal face of one of the ribbed rings of Fig. 2.
4. Distal face of the same ring.
5. Segment of proximal face of young stem joint fitting upon face of Fig. 4.
6. Segment of the distal face of a similar younger joint of an adjoining ring.
7. Reticulation from the centre to the base of the ribs.
8. Indistinct pentagon forming opening for axial cord.
9. Reticulation round the axial ring.
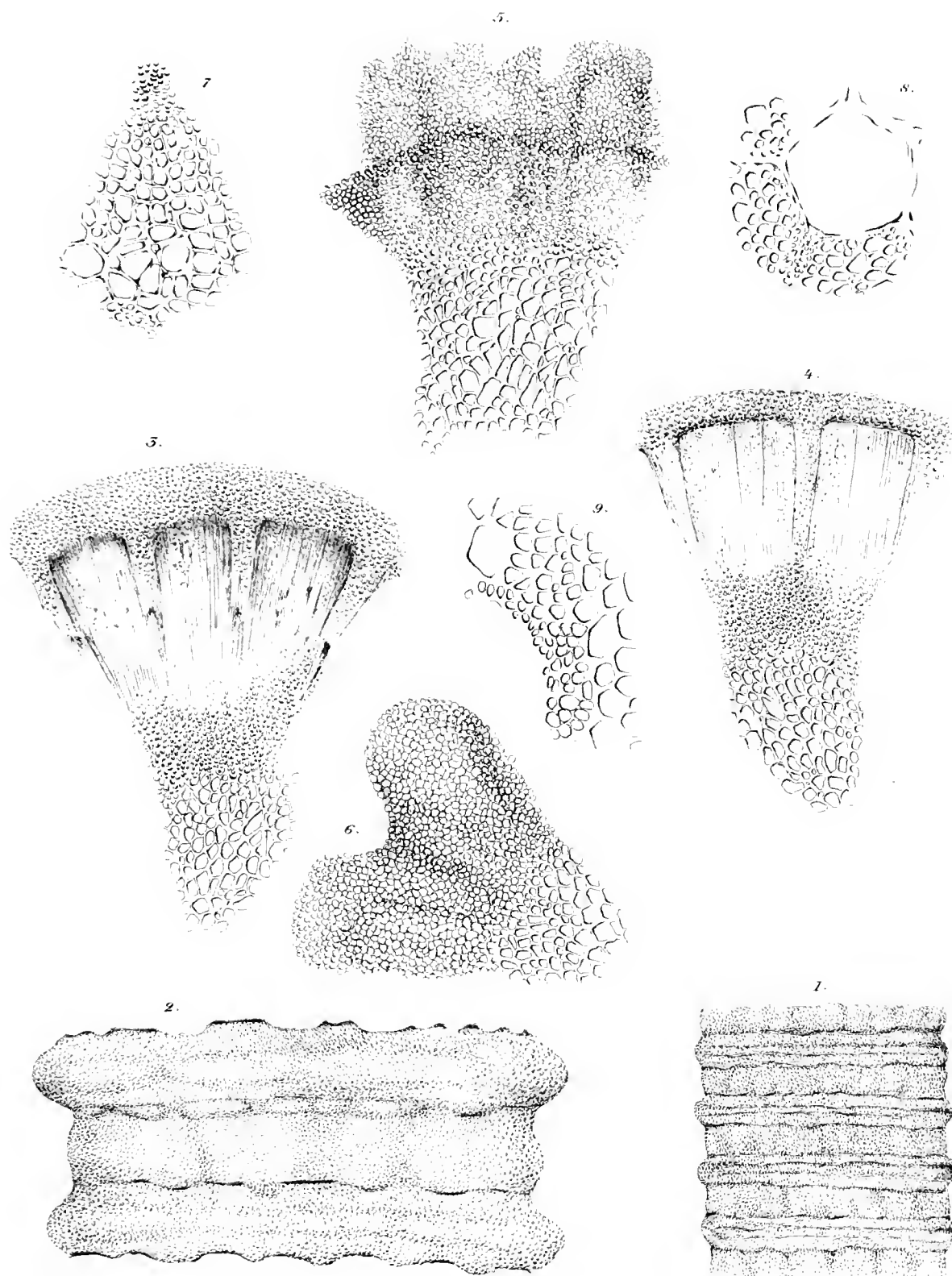
# PLATE XXIII.

1. Transverse view of upper part of stem. see Plate XXII. Fig. 1, with ribbed and flat rings, to show the position of new rings intercalated between the old ones.
2. The outer edge of two rings showing the new joint coming to the surface.
3 Oblique view of a segment of two adjacent rings, with the intercalated new young joints.
4. Sketch of two new joints, one of which has extended to the outer surface of the stem.
5 An oblique view of a ribbed joint with a segment of a new joint in place inside of the serrations of the joint.
6. The distal view of the new ring, forming on the top of the ribbed joint in Fig. 5.
7. Segment of a new ring resting upon the face of Fig. 8.
8. Portion of the edge of a ribbed ring showing the crenulations to the edge of the new ring.
9. The distal face of the upper joint of Fig. 4 after the removal of the young joint, showing the seat for the new joint.
10. Reticulation of the central part of an old ring adjoining the axial cord.
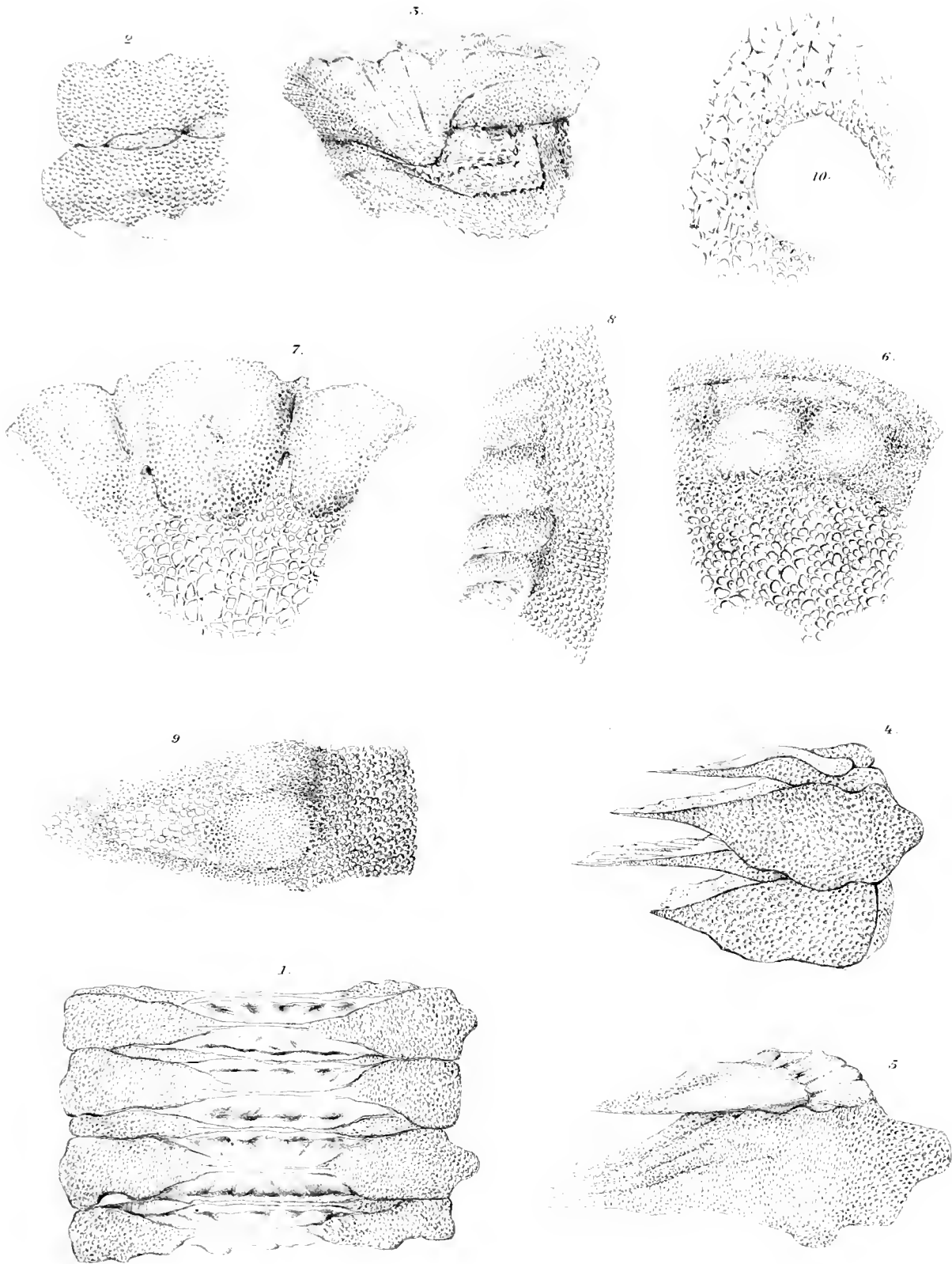
# PLATE XXIV.

1. Segment of distal face of ring, showing the seat of the new joint.
2. The proximal face of the same ring.
3. A segment of a ring in which the radiating ridges have become quite numerous, with the seat of a new ring.
4. Segment of new ring reaching the outer edge.
5. Profile view of same young ring.
6. Section across two rings, showing the position and shape of a new ring.
7. A ribbed and a flat ring in the middle part of the stem with a very young ring.
8, 9, 10. Young rings seen in profile fitting between the older rings, and not yet extending to the outer surface.
11. Oblique view of reticulation round the opening of the axial cord of two adjoining rings.
12. Outline of reticulation round the axial opening of another ring.
13. Thickened edge of the opening for the axial cords.
14. A few of the meshes of the central part of the reticulation greatly enlarged.
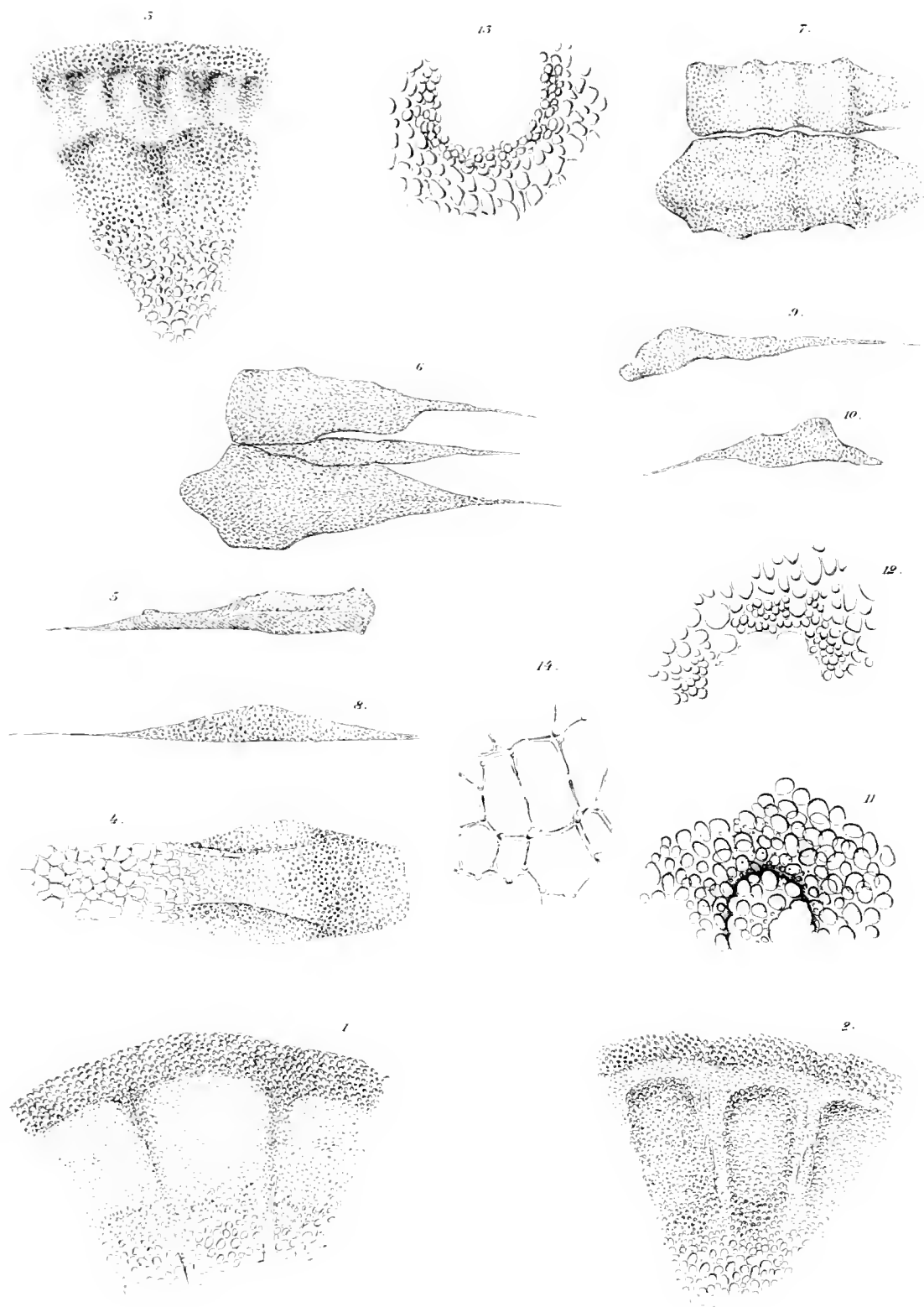
# PLATE XXV.

1. Two rings of a part of the stem corresponding to that of Fig. $5^e$, Plate XVIII.
2. Transverse view of two rings from the same part of the stem.
3. Proximal face of segment of one of the above rings.
4. Distal face of a ring on a part of the stem a few rings above.
5. Sutures of a part of a ring in which the serrations are coarser than in Fig. 1.
6. Portion of face of same ring, in which the radiating ridges are quite numerous.
7. Transverse section of same ring, showing the thickening of the outer edge, with a comparatively large axial canal.
8. Axial fibrillæ and facial muscular ligament connecting faces of adjoining rings.
9. Ring from a part of the stem corresponding to that of Fig. 7, Plate XVIII.; the outer serrations have nearly disappeared.
10. Irregular serrated plates forming the radiating ridges from the middle third of the face of the joint.
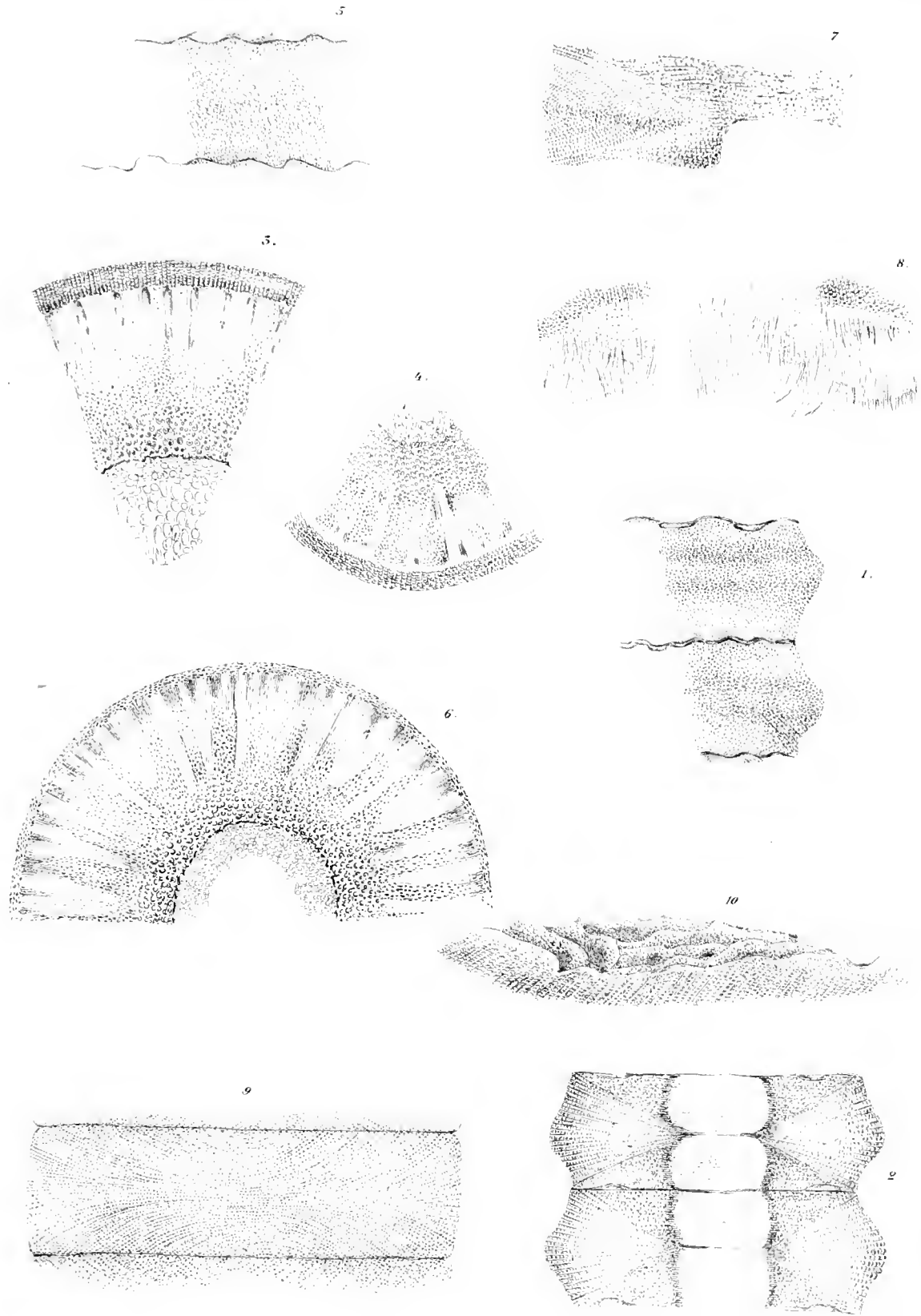
# PLATE XXVI.

1. Exterior portion of a joint near the middle of Fig. 5, Plate XVIII.
2. Distal face of the joint of Fig. 1, showing the formation of circular rings in the central part of the face of the joint.
3. Magnified segment of part of same face as Fig. 2.
4. Oblique view of radiating lamellæ near outer edge of Fig. 3.
5. Distal face of the fourth joint from upper end of Fig. 9, Plate XVIII.
6. Magnified segment of same face as Fig. 5.
7. Transverse optical section of joint (Fig. 1), showing arrangement of the reticulation in irregular curved lines, extending from one face to the other.
8. Magnified view of the calcareous reticulation of the inner part of the joint.
9. Segment of face of ring, three joints from the lower end of Fig. 9, Plate XVIII. The radiating ridges have become irregularly radiating lamellæ, which are not continuous from the periphery to the central axial canal.
10. Oblique view of a part of the outer edge of the face of the same ring.
11. Part of suture of upper joints of Fig. 11, Plate XVII., greatly magnified.
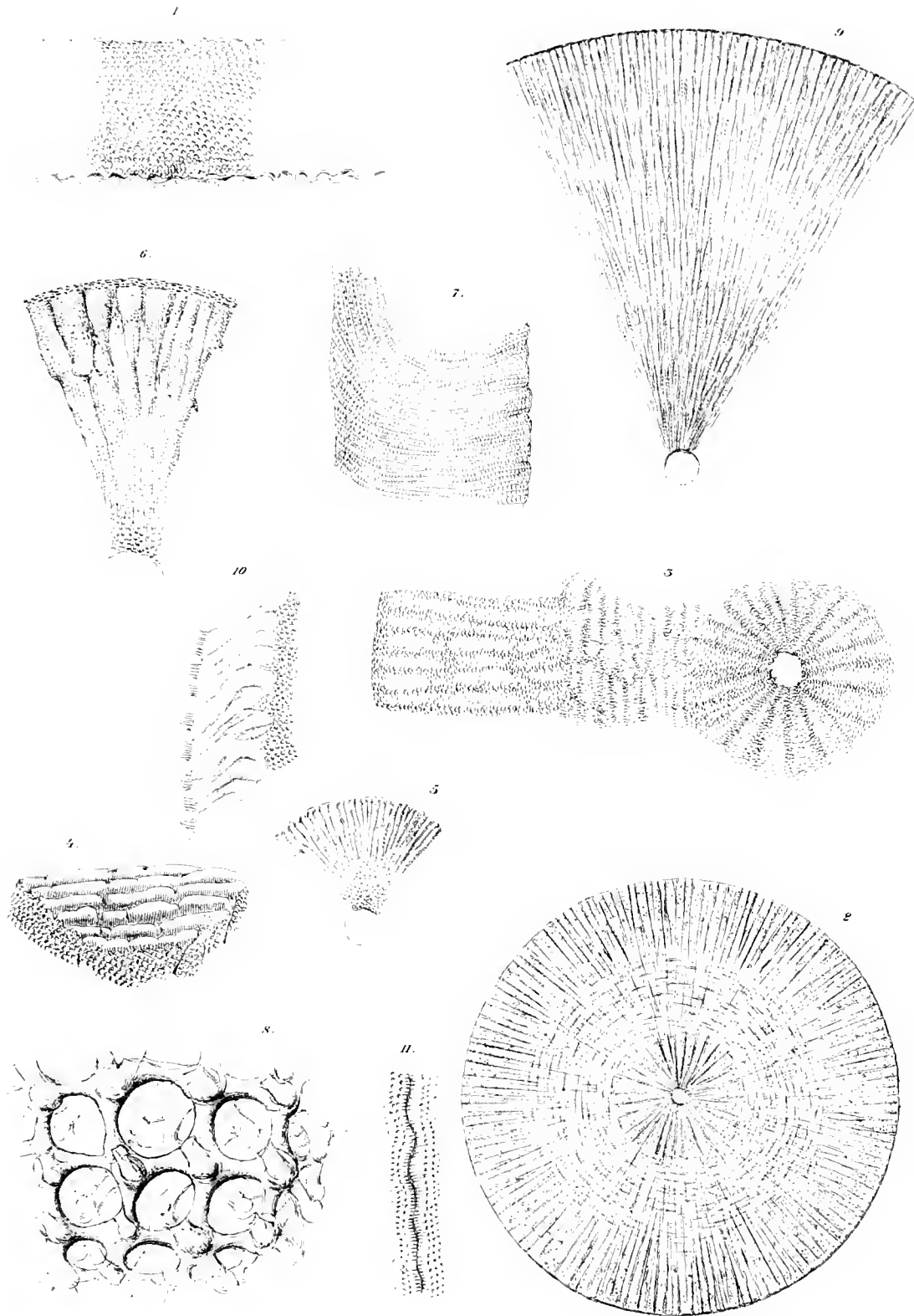
# PLATE XXVII.

1. Section through pinnule joint.
2. Section through arm joint.
3. Edge of same, somewhat more magnified.
4. Section across top of first radial.
5. Longitudinal section of joint near the middle of the stem (Plate XVII. Fig. 12, a).
6. Transverse section of joint near base of stem (Plate XVIII. Fig. 9, a).

These figures are from photographs by Dr. R. R. Andrews, taken from sections made by Dr. Hensoldt, of the Columbia School of Mines.

PLATE XXXII
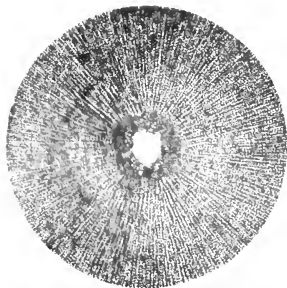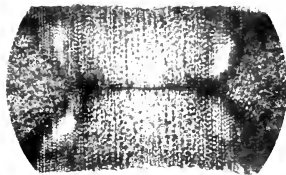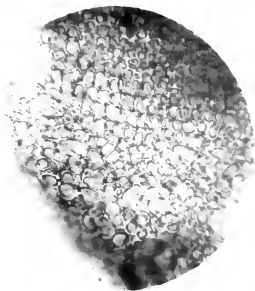
# PLATE XXVIII.

1. Calamocrinus Diomedæ, natural size, seen facing the right posterior interambulacrum.
2. Piece of stem, natural size.
3. Basal part of same, showing the expansion of the last joints ; asymmetrical view.
4. Symmetrical view of basal joints of same.
5. Enlarged view of upper part of stem.

   Specimen from 782 fathoms, Station 3357, off Mariato Point, February 24, 1891.

# PLATE XXIX.

## ABACTINAL SYSTEM OF

1. Bothriocidaris Pahleni, copied from Schmidt.
2. Palæchinus elegans, copied from Bailey.
3. Goniocidaris biserialis, copied from Döderlein.
4. Leiocidaris imperialis, copied from Döderlein.
5. Porocidaris Sharreri, copied from A. Agassiz.
6. Goniocidaris geranioides, copied from A. Agassiz.
7. Phyllacanthus baculosa, copied from A. Agassiz.
8-10. Dorocidaris papillata, copied from A. Agassiz.
11. Dorocidaris Blakei, copied from A. Agassiz.
12. Dorocidaris Bartletti, copied from A. Agassiz.
13. Aspidodiadema tonsum, copied from A. Agassiz.
14, 15. Aspidodiadema Jacobyi, copied from A. Agassiz.
16. Aspidodiadema microtuberculatum, copied from A. Agassiz.
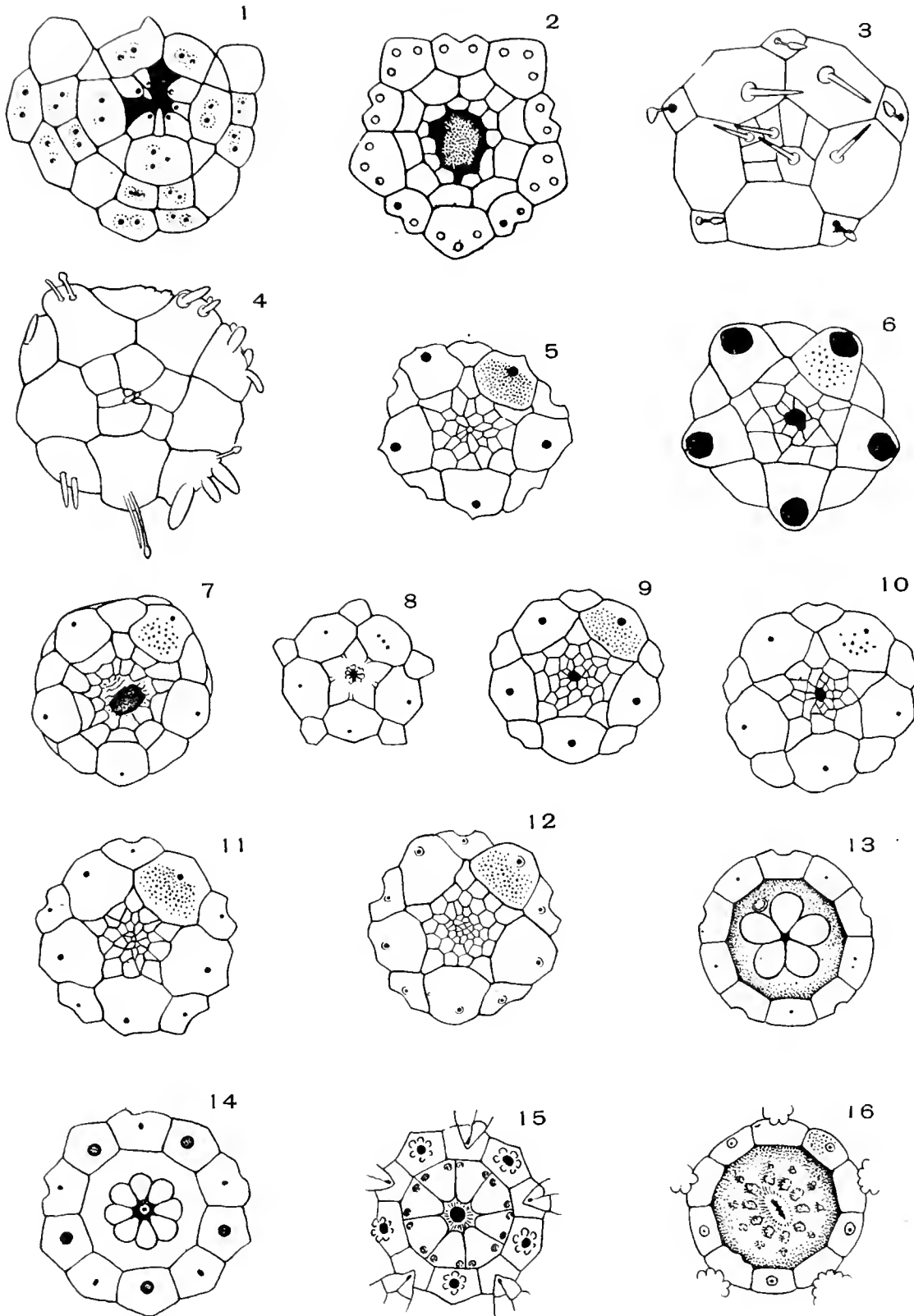
# PLATE XXX.

### Abactinal System of
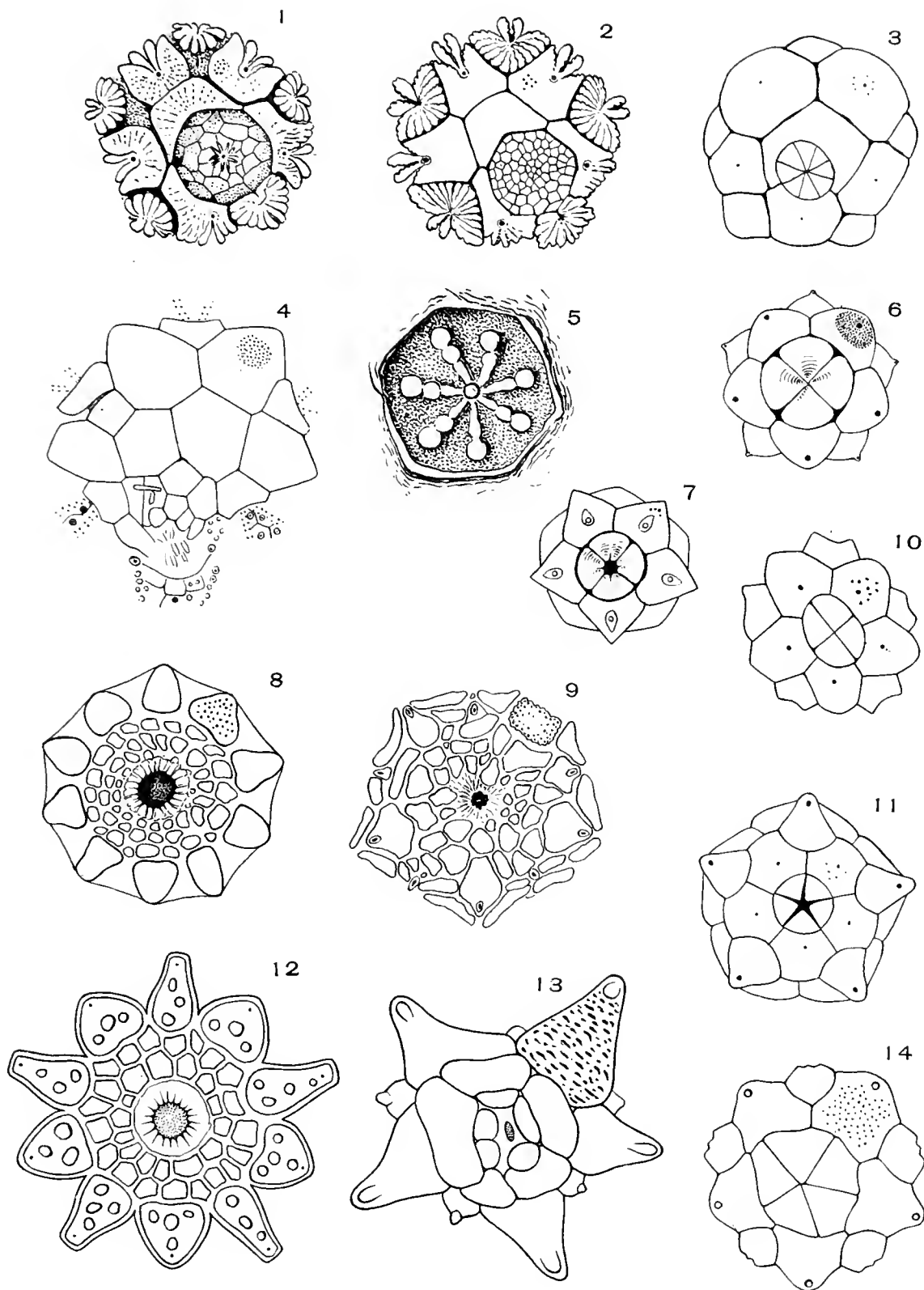
PLATE XXX.

# PLATE XXXI.

### Abactinal System of

1. Parasalenia gratiosa, copied from A. Agassiz.
2. Temnopleurus Reynaudi, copied from A. Agassiz.
3. Temnechinus maculatus, copied from A. Agassiz.
4. Trigonocidaris albida, copied from A. Agassiz.
5. Trigonocidaris monolini, copied from A. Agassiz.
6. Pleurechinus bothryoides, copied from A. Agassiz.
7. Strongylocentrotus Dröbachiensis (anal plate), copied from A. Agassiz.
8-10. Toxopneustes variegatus, copied from A. Agassiz.
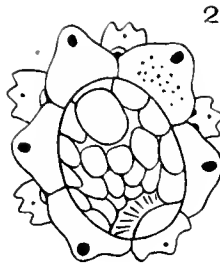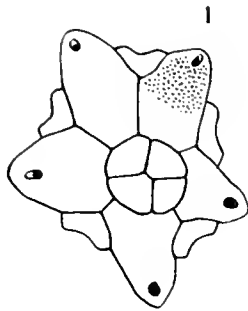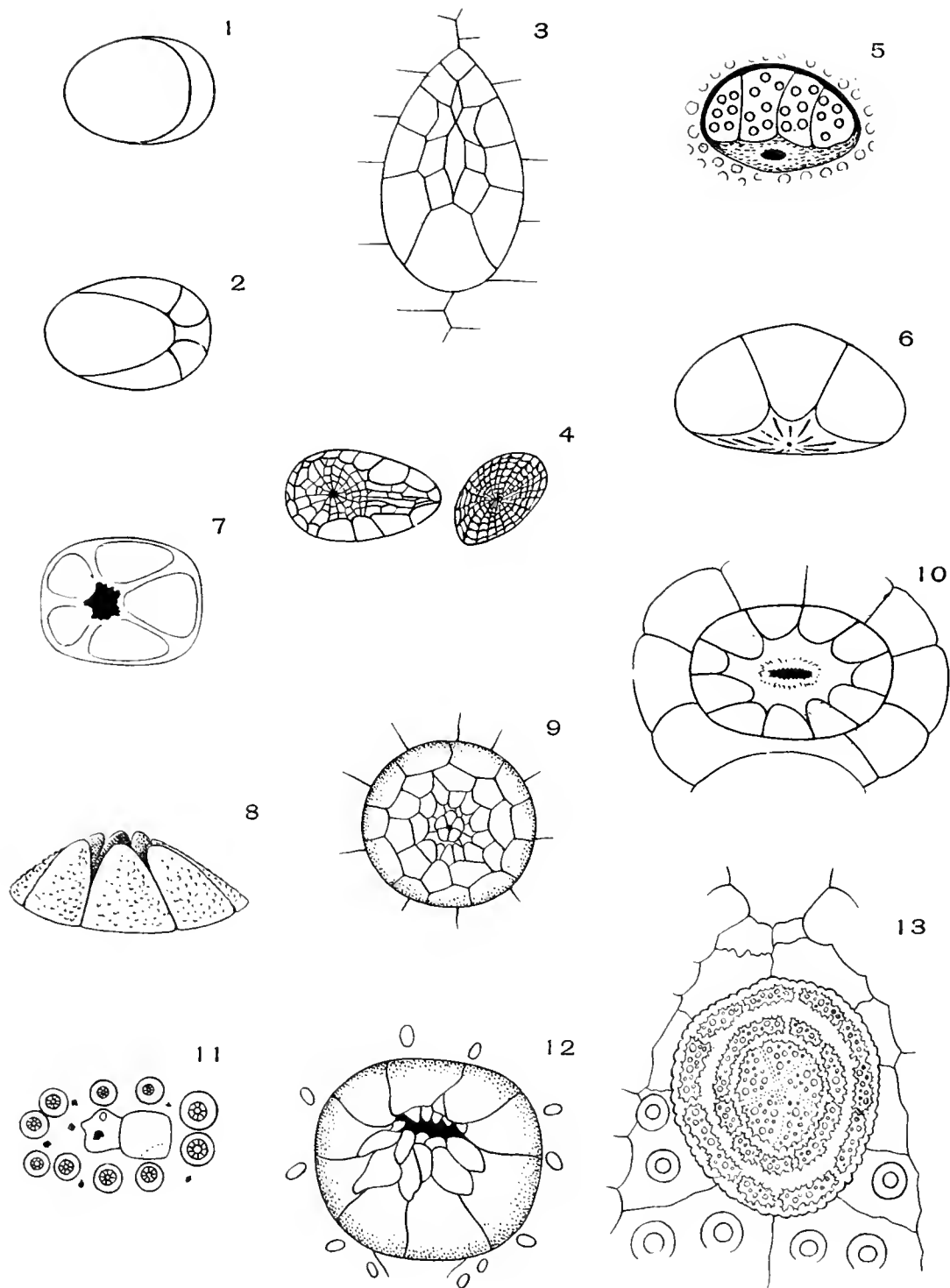11. Echinus horridus, copied from A. Agassiz.
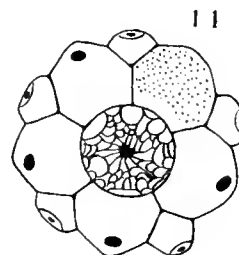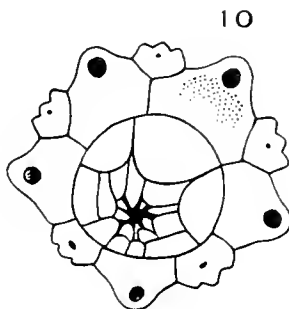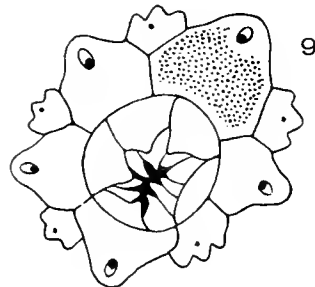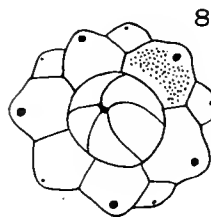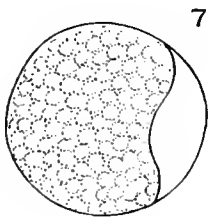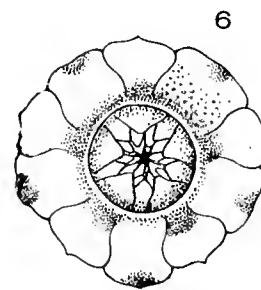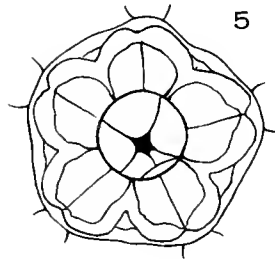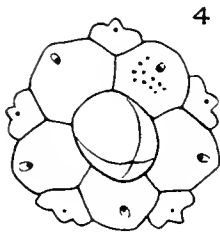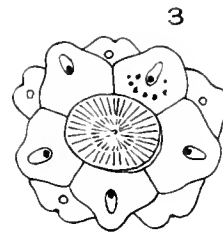
PLATE XXXI.

# PLATE XXXII.

## ANAL SYSTEM OF

1, 2.  Echinarachnius parma, copied from A. Agassiz.

3.  Discoidea cylindrica, copied from Cotteau.

4.  Echinonëus semilunarius, copied from A. Agassiz.

5.  Echinolampas Hellei, copied from A. Agassiz.

6.  Echinolampas depressa, copied from A. Agassiz.

7, 8.  Neolampas rostellata, copied from A. Agassiz.

9.  Palæobrissus Hilgardi, copied from A. Agassiz.

10.  Urechinus naresianus, copied from A. Agassiz.

11.  Hemiaster cavernosus, copied from A. Agassiz.

12.  Cystechinus Wyvillii, copied from A. Agassiz.

13.  Echinocardium flavescens, copied from Lovén.

PLATE XXXII.